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(Founded 1866*)*

with which is incorporated the Institution of Aeronautical Engineers

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The 596th Lecture to be read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS

A meeting of the Society was held in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, on Monday, November 4th, 1935, when Mr. B. Lockspeiser, M.A. (Royal Aircraft Establishment), presented a paper on "The Prevention of Ice Accretion." In the chair, Mr. D. R. Pye, M.A., F.R.Ae.S., Member of Council.

The CHAIRMAN: The problem of preventing ice accretion was one of much importance in this country and of even greater importance in some other countries and continents. In the past a great deal of work had been done of a rough and ready character; trials had been made of methods such as leading heat to parts of the aircraft on which ice was apt to form, making false leading edges which could be inflated in order to crack the ice which had formed and so enable it to be blown away, and smearing certain parts of the surface with all sorts of nasty mixtures. One such mixture referred to in the paper was glue, treacle, Castile soap and common salt.

The success of Mr. Lockspeiser's work was largely due to his having gone back to the basic physical conditions which were necessary to arrive at some form of surface treatment which would not be scraped or washed away during the first ten minutes of flight of the machine to which it was applied. The meeting would probably agree, after having heard Mr. Lockspeiser's description of his proposed method of preventing ice accretion, that it looked like being a successful solution of the problem.

Mr. Lockspeiser, after a distinguished career at Cambridge, had served during the war in Gallipoli and in Egypt. Later he had worked at the Admiralty Laboratory at Sheffield and in the Inventions Department of the Ministry of Munitions. In 1921 he had joined the staff of the Royal Aircraft Establishment, where he had worked since then and where he now held an appointment as a Senior Scientific Officer.

THE PREVENTION OF ICE ACCRETION

BY

B. LOCKSPEISER, M.A.

Introductory

Flying, in common with all means of transport, is affected by adverse weather conditions, but the necessity of aeroplanes to maintain flying speed introduces a major difficulty of its own. The older forms of transport are able, in the last resort, to evade their difficulties by coming to a dead stop. An aeroplane must, literally, fly in the face of its difficulties. It must fly blind in clouds and perhaps

land in fog. Over and above this, flight under certain meteorological conditions introduces a danger unique to aircraft. Ice may deposit at all leading edges and grow to windward, at critical regions of the relative airflow, in shapes which increase drag and seriously decrease lift. The accumulated ice adds to the weight. Unsymmetrical ice deposits on the airscrew blades cause dangerous engine vibrations which can only be kept in check, if at all, by throttling back at the expense of thrust. Venturis and pressure head orifices become blocked with ice, rendering the instruments they serve useless. External controls may become jammed. In short, many adverse factors to prevent flight may be brought into play simultaneously by the mere fact that particular meteorological conditions have been encountered.

Under these conditions, ice may build up rapidly. The danger to which aircraft are exposed is an obvious one, and in the present stage of aeronautics, when cloud flying is of tactical importance and air routes require to be operated regularly, the importance of the problem needs no emphasis.

Meteorological Conditions Favourable to Ice Formation

The meteorological conditions under which ice may accrete on aeroplanes and the character of the ice deposits, which themselves vary with the conditions, have been the subject of considerable study in various countries and much has been published in recent years. Reference is made to the bibliography attached to this paper. It is not the purpose of this address to enter, in any detail, into the meteorological aspect of the problem. Not that this is unimportant. Other considerations apart, reliable meteorological predictions as to the probable encountering of ice conditions in flight and a knowledge of the extent of the area, with, possibly, the shortest cut to safety, are valuable aids. But, whatever may have been the position in the past, the solution of this problem in the present stage of aeronautics, calls for more than meteorological aids. There are three reasons why this is so:—

(*a*) Bombing aeroplanes choosing the cover of clouds will frequently find themselves in strato-cumulus formation which by their tendency to extend unbroken at certain times of the year, for hundreds of miles at about 2,000-5,000 feet, offer the necessary tactical advantages. This type of cloud, more than any other, is associated with ice forming conditions.

(*b*) The regular operation of air routes, in many parts of the world involves the necessity, from time to time, of flying through ice forming conditions.

(*c*) The aeroplane may be so heavily and quickly handicapped by flight in severe ice forming conditions, that its reduced performance may not be high enough to take it to regions of safety. Under these conditions a forced landing is the only way out.

From the mass of evidence collected in recent years as to the particular meteorological conditions and the associated ice deposits, the following broad conclusions may be summarised:—

(1) In the main, ice forms only at leading edges whence it builds forward and outwards. At times the whole wing surface may become covered with a light frost or glassy ice film and icicles may appear at the trailing edge.

(2) Ice dangerous to aircraft, forms only when visible moisture is encountered in the form of rain, mist, cloud or fog.

(3) The heaviest rate of accretion of ice is due to rain falling from a warmer stratum of air on an aeroplane flying in a colder region whose temperature is below freezing point. The air temperature at the height of flight is usually, under these conditions, not more than two or three degrees below 0°C. Clear ice, hard and glassy, is invariably formed under these conditions.

(4) Super-cooled droplets of water may exist in mist, cloud or fog down to −20°C. On contact with leading edges instantaneous freezing takes place. Because the moisture content of air masses decreases with lowering of temperature, air temperatures just below the freezing point are most conducive to rapid ice accretion. Ice formed under these conditions is usually white and opaque, granular in structure. Clear ice may also be deposited under these conditions.

(5) Both clear and opaque ice adhere strongly to the surfaces on which they are deposited in flight. The adhesion of clear ice is, in general, greater than that of the opaque variety.

(6) The deposition of clear ice often gives rise to irregular flattish shapes of increased frontal area at the leading edge (see shapes recorded by Carroll and McAvoy (Ref. 6)). Fig. 6 shows a sketch of a section of ice of this type taken from the strut of a Gordon aeroplane on landing after a flight in 10/10 strato-cumulus cloud at −3°C. in the neighbourhood of Farnborough.

(7) White opaque ice tends usually to build forward into crescent shapes, less dangerous immediately than the shapes associated with clear ice, but sufficiently so to impair performance and lead to forced landings eventually.

(8) The temperature range favourable to the most rapid formation of either clear or opaque ice is within a few degrees below 0°C.

Methods of Prevention

Three possible methods whereby the accretion of ice on aeroplanes may be prevented have emerged from the very considerable body of experimental work already carried out on this problem, (*a*) thermal, (*b*) mechanical, (*c*) chemical. These will be considered in turn.

(*a*) *Thermal Method.*

Although the ice deposit is normally confined to leading edges, it is found that, if the nose of a wing alone is maintained above 0°C., the water is blown back and freezes in ridges parallel to the chord. Theodorsen and Clay (Ref. 7) who made a full-scale investigation of this method, provided a slot, running along the span in the neighbourhood of maximum wing thickness, to catch the water, and means for draining the slot in flight. There are obvious aerodynamic objections to such a course, and there is little doubt that the successful application of the thermal method of preventing ice accretion involves the provision of heat for raising the temperature of the entire wing.

How much heat would be required for this purpose? The amount, of course, depends on wing section and air speed. From wind tunnel tests on a R.A.F. 48 section, M. Scott (Ref. 8) estimates that a monoplane of 40ft. span, average chord 6.7ft., at an air speed of 180 m.p.h., requires 144 h.p. to maintain the wing 20°C. higher than the surrounding air. This figure is comparable with those deduced from other experimental work. It is clear that the order of the quantity is such that we must look to either the jacket or exhaust heat as the source of supply.

The evidence also points to a direct rather than an indirect use of these sources. From time to time schemes are put forward for leading warmed air from muffs round the exhaust pipe to the interior of the wing. The fundamental difficulty here is that the necessary rates of heat transfer, in all stages, from the exhaust gases to the wing, can only be obtained by piping of large surface areas involving weight considerations and constructional difficulties such as to render these schemes entirely impracticable. The thermal method is unsuitable for application to existing aircraft and must be considered in relation to the thick section all-metal monoplane of the future.

The direct method of using the jacket or the exhaust heat involves, in the one case, wing surface radiators and, in the other, the discharge of the exhaust through orifices along the span from a pipe integral with the leading edge. As regards wing surface radiators it would be desirable to use them in conjunction with evaporative engine cooling, for the tendency of vapour to condense at the coolest places promotes uniformity of wing heating. Part of the vapour in the system could be by-passed to dissipate its heat in the tail unit. Apart from preventing ice accretion, wing surface radiators carry with them the advantage of eliminating the parasitic drag of the normal radiator. This method of using the jacket heat for preventing ice accretion appears attractive, but the attendant plumbing difficulties cannot be lightly disregarded and, from a military point of view, an aeroplane carrying such a system may be more vulnerable.

The discharge of the exhaust gases at wing leading edges is by no means plain sailing. There is the danger of corrosion allowing the hot gases to play on the wing structure, the proximity of the petrol tanks in the thick metal wings, the possibility of an explosive charge entering the wing nose and the necessity for allowing free movement of the nose to allow for differential thermal expansion. These are formidable difficulties though not, perhaps, insuperable. On the other hand, there are the advantages of reduction of exhaust noise, the elimination of the parasitic drag of external exhaust pipes, and, as Mr. F. W. Meredith, of the Royal Aircraft Establishment, suggests, an appreciable net drag reduction is to be expected from discharging the hot gases at the front stagnation region of the main surface.

Much remains to be done before heat normally running to waste can be harnessed for the prevention of ice accretion, but because the utilisation of this heat carries other advantages which assume greater importance as design becomes cleaner, it is not improbable that aircraft of the future may solve the ice problem on these lines.

(*b*) *Mechanical.*

A mechanical method of dislodging ice is described by Geer and Scott (Ref. 9) and Scott (Ref. 8). A pulsating movement is induced in a rubber "overshoe," fitted over the leading edge along the whole length requiring protection, by the inflation of one or more rubber inner tubes. The rubber overshoe is treated with an oil mixture which, it is claimed, reduces the adhesion of ice. The regular pulsation of the overshoe by compressed air enables the ice to be broken up and blown away in the wind.

More recently wing overshoes operated by three inflatable inner tubes have been used in America on postal aircraft. It is understood that the wing overshoes are not treated with oil as originally recommended by Geer and Scott. As regards the airscrew, rubber sheeting is firmly attached to the spinner, and to the blades on their thrust side, around the leading edge and back on the convex side to approximately the line of thickest section. The rubber in this case is impregnated with the oil mixture before flight. It is claimed that the whole equipment gives satisfactory results.

(*c*) *Chemical.*

There is one certain way of reducing the adhesion of ice to a small value—by ensuring that the super-cooled water mixes at the surface of contact with a substance which depresses the freezing point of water sufficiently to maintain a liquid boundary layer. For this purpose liquids miscible in water in all proportions are very much superior to water soluble solids, on account of the more rapid rate of mixing of the former. A large proportion of the early work devoted to the problem of ice prevention was directed towards finding a hard, water soluble coating of this nature, which could be painted on the leading edges before flight, and some success was obtained both in tests in the refrigerated

wind tunnel and in flight. Knight and Clay (Ref. 10) found that " hard soluble substances such as glucose and karo syrup, which hold their shape and adhere strongly to the surface, prevent ice formation within certain temperature limits, depending on their solubility." Wind tunnel experiments at the Royal Aircraft Establishment demonstrated the usefulness of anti-ice dopes consisting of mixtures of glue, treacle, Castile soap and sodium chloride. Flight tests under ice formation conditions were made with these mixtures painted on selected parts of wing leading edges, visible to the pilot, for comparison to be made with untreated parts. The general inference from a considerable number of flight tests was that ice formed initially on both treated and untreated edges, though not necessarily at the same rate, and that when the ice deposit reached a certain thickness it blew off in the wind. This process might be repeated two or three times until the efficacy of the coating was exhausted. Typical extracts from pilots' reports on these flight tests are given below.

> (*a*) " Ice accreted on all leading edges to the extent of $\frac{1}{4}$ inch. It was noticed that the ice fell off the surfaces coated with chemical mixture. The impression was that the coated surfaces accreted until the grip failed to hold the ice, which blew off."
>
> (*b*) " Ice quickly commenced to form on all leading edges, struts, planes, wires, etc. The quality of the ice was white, hard and opaque, and the total amount built up was about $\frac{3}{8}$in. After building up on all leading edges equally, whether coated with the chemical mixture or not, the ice commenced to drop off the treated surfaces in large pieces and did not appear to build up again in any quantity."

The application of anti-ice dopes to leading edges to prevent ice accretion is, however, hardly a practical solution of the problem. The protection afforded is limited by the small quantity of dope possible to be applied, which may, of course, be washed off by rain before encountering ice, and the method involves the necessity of making preparations before leaving the ground. But the experienced gained from these flight tests was valuable for the demonstration that it is not necessary to provide an anti-freezing substance in sufficient quantity to melt all the ice. It is only necessary to maintain a liquid boundary layer at the surface of contact.

The obvious requirement to transform this principle to a successful practical method is a porous leading edge which can be saturated, at the will of the pilot, with a liquid possessing a strong effect in depressing the freezing point of water, and through which the liquid can be made to flow uniformly, at a variable rate within limits according to the conditions. The quantity of liquid required, if discharged economically (all forms of spraying must be avoided), is not excessive, for the worst conditions occur only two or three degrees below o°C. and the concentration of anti-freezing liquid in the boundary layer necessary to maintain this small depression of the freezing point of water is low. At low temperatures the larger concentrations of liquid required to produce the depression of the freezing point is offset by the lower rates of ice formation.

Any practical method of achieving a porous wing nose must provide for a hard wearing serviceable substance which, in both the dry and wet state, keeps its shape. Moreover, fitting as a whole must not impair appreciably the aerodynamic characteristics of the wing. To meet these requirements specially tanned leather was selected as the outer porous covering to which liquid is fed continuously from the inside through a perforated rubber tube.

Method of Construction of Anticer

Fig. 1 shows the details of construction. A layer of rubbered fabric (A) is doped to the wing with the rubbered surface uppermost. The liquid is conveyed by a rubber tube B, punctured at $\frac{1}{4}$in. intervals along its length. The tube is

made to adhere to the leading edge partly by rubber solution and partly by a plastic cement or rubber sponge which serves also to fair off the edge. (C) is a porous cotton fabric layer which spreads the liquid to wet the leather covering (D). Attached to the leather are strips of aeroplane fabric (E) which, when doped to the wing, hold the leather covering firmly in place. The diagram is intended only to illustrate the principle. In practice the leather is bevelled to avoid the step down to the wing surface and, generally, the finish is as clean as possible.

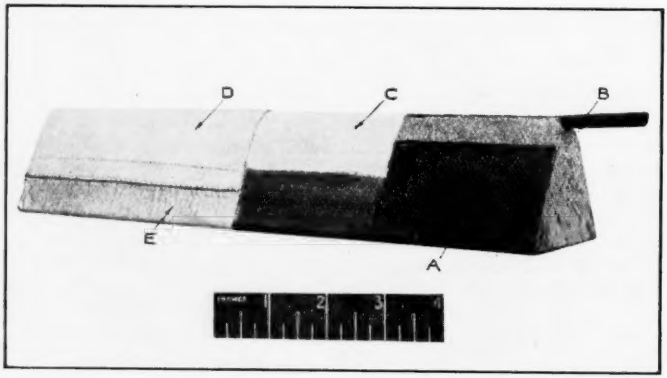

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FIG. 1.

Detail of anticer construction.

Fig. 2 shows a Hart aeroplane equipped with the anticers at leading edges, and Figs. 3 and 4 are near views of the fitting on the wing and tail respectively. The change in shape of the wing section due to the fitting is small enough to be negligible.

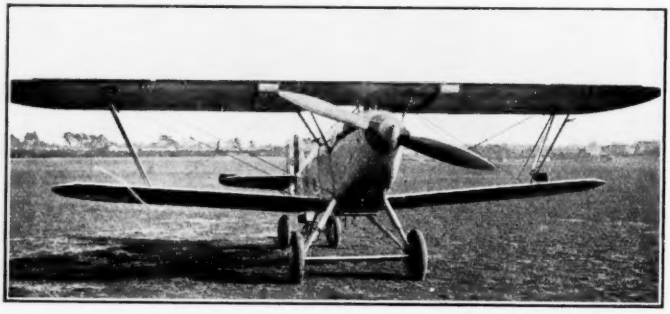

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FIG. 2.

Hart equipped with anticers.

The liquid is supplied to the perforated rubber tubing under pressure, by means of light piping to the parts of the aeroplane requiring protection. Since the flow of liquid is small the system is effectively under hydrostatic pressure and the flow at all parts is approximately uniform.

The liquid container may be connected through a reducing valve to an existing pressure supply (such as a compressed air bottle for operating brakes or an oxygen bottle) without depleting the supply appreciably. If no convenient source of pressure is available, either a bottle partially filled with the liquid under pressure or a small pump may be used. In all cases the flow, indicated on a simple flow meter of the moving vane type, is under the control of the pilot.

Choice of Liquid

A suitable liquid should satisfy the following requirements:—

(*a*) Low setting point.
(*b*) Miscible in all proportions with water.
(*c*) Large effect in depressing the freezing point of water.
(*d*) Low vapour pressure below 0°C.
(*e*) High flash point.

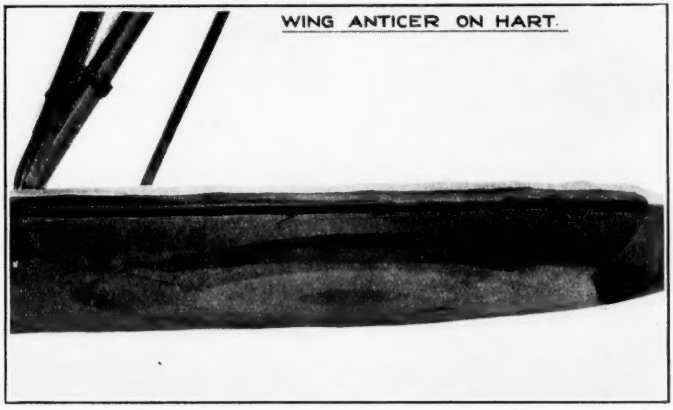

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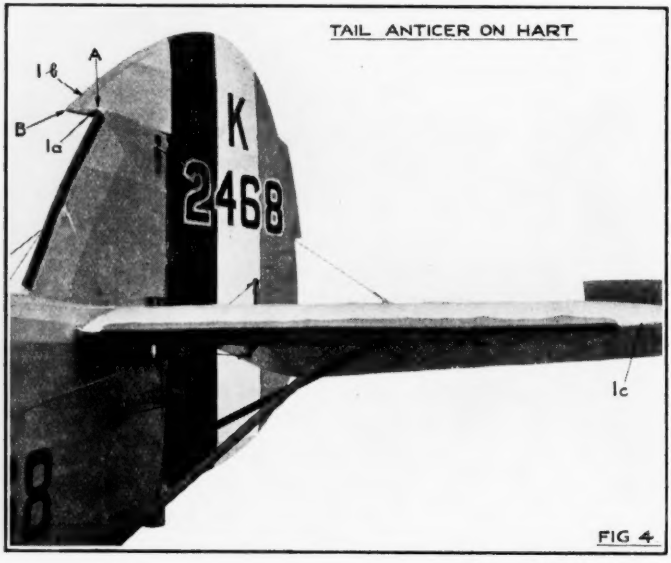
FIG. 3.

Ethylene glycol is a suitable liquid. Its effect in depressing the freezing point of water is shown in the liquid solid equilibrium diagram of mixtures of ethylene glycol and water (Fig. 5). Its flash point is 125°C. and vapour pressure 0.02 mm. of mercury at 0°C. Its setting point (−18°C.) is, however, too high for use at the lowest temperatures of ice formation. This may be reduced by mixture with other liquids. Ethyl alcohol (10 per cent. by volume) lowers the setting point to −24°C., but the flash point is lowered also to 60°C; 10 per cent. butyl carbitol lowers the setting point to below −30°C., the flash point remaining as high as 118°C. The depression of the freezing point of water is increased somewhat by the addition of 10 per cent ethyl alcohol, but 10 per cent butyl carbitol makes very little difference. Both ethylene glycol itself and a 10 per cent. ethyl alcohol mixture with glycol have been used with success in flight.

Test Flights

The anticer has been tested under ice forming conditions on both Hart and Gordon aeroplanes. On one occasion when a thickness of 1in. of ice was built up on the struts of the Hart aircraft, illustrated in Fig. 2, an observer who kept the tail unit under close observation reported:—"After being at −2°C. for some minutes ice was noticed forming on various parts of the aircraft, *e.g.*, bracing wires, struts. It then began to form on the tail unit, firstly, on the

unprotected parts in positions labelled 1a, 1b and 1c, on Fig. 4. (As regards 1c, ice actually formed not on the port side but in the corresponding position on the starboard side.) After some time it was noticed that patches of ice were forming on the protected edges, starting with that on the fin. These patches appeared suddenly and having appeared did not grow at an appreciable rate. Roughly, 10 sq. ins. of surface of the fin were covered and about 6 sq. ins. of the starboard side of the tail plane. In no case was any ice seen on the port side of the tail plane. After persisting for a few minutes the ice patches suddenly disappeared from the protected parts. These would then be free for a considerable time. Actually during the one hour duration of the flight ice formed on



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three occasions only. In every case the ice was more persistent on the fin than on the tail plane. No ice formed on the half of the protected parts nearest the fuselage of the aircraft.

" Meanwhile the other parts of the aircraft were accumulating ice, with the result that by the conclusion of the flight about one inch had been collected on bracing wires, etc. In particular large accumulations occurred on corners, such as the corners of the fin and balanced portion of the rudder (labelled A and B respectively) and also on the horn of the elevator."

The consumption of ethylene glycol for the whole aeroplane was 1.5 pints per hour.

On another occasion a second observer reported similar behaviour of the anticers. Either (*a*) ice is thawed as quickly as it forms, or (*b*) ice adheres in places and after a few minutes its adhesion is destroyed and blown away. The rate of flow of the ethylene glycol appears to determine which phenomenon is observed. With a very small flow (*b*) takes place—a film of ice forming over the whole of the leading edge or in patches where the flow is restricted because of irregularities in the perforations or of variations in the porosity of the leather. When sufficient ethylene glycol has accumulated at the interface of the leather

and ice, the latter breaks away. With a larger flow of liquid, ice, apparently, does not adhere under any of the conditions so far encountered.

A test flight under heavy ice forming conditions was also made with a Gordon aeroplane fitted with anticers on the leading edges of wings, tail planes and fin. The liquid was turned full on for some minutes, sufficient to saturate the leather, before entering ice forming conditions and then turned off. Flight was maintained under these conditions for 30 minutes when the liquid was turned on and flight continued for a further 30 minutes. Ice built up on the struts to a depth of $2\frac{1}{2}$-$3\frac{1}{2}$ins. The pilot reported:—

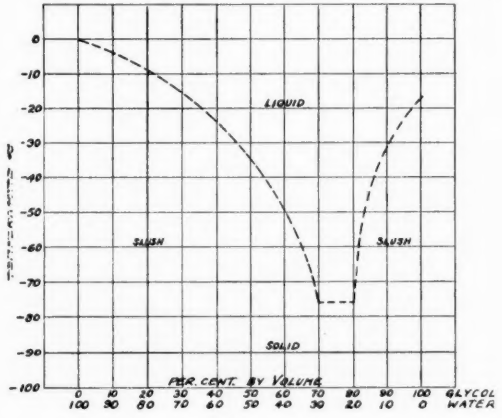

FIG. 5.

Equilibrium diagram of ethylene glycol and water.

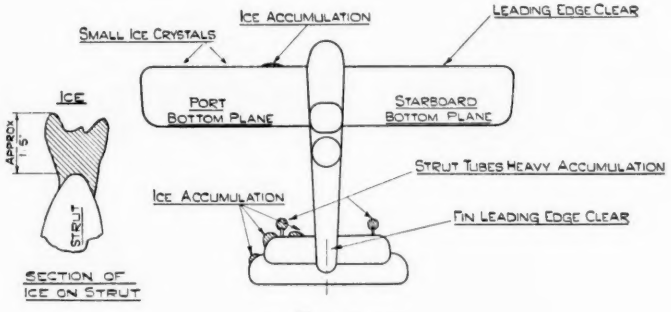

FIG. 6.

Illustrating anticer test flight.

"Aircraft flew in 10/10 strato-cumulus cloud in a temperature of $-3°$C. at 3,300ft. for approximately 30 minutes with the anti-ice accretion solution turned off. Ice built up slowly, as shown in the accompanying sketch (Fig. 6), on the leading edges of the struts to a fairly uniform depth of $2\frac{1}{2}$ to $3\frac{1}{2}$ inches. A quantity of slightly less depth was obtained on the wires, but this continually broke away and built up again on account of vibration. From the pilot's seat, ice could be seen building up slightly on the leading edges of the port lower and upper main planes and port side of tail plane.

" No ice appeared to form on the leading edge of the starboard bottom or top plane or on the leading edge of the fin.

" Of this ice accretion on the plane surfaces, four points were specially noticeable :—

(*a*) As a whole, ice accretion was of small quantity compared to that on struts and wires.

(*b*) There were two exceptions to (*a*) where ice built up to 2in. or 3in. depth, and that was on port lower plane leading edge at distance of about 3ft. from the root and on leading edge of port tail plane about 1ft. from root and at extremities. (These distances are quite approximate.) It was noticeable that on both sides of tail plane, a heavy accretion of ice built up on stub tubes projecting from leading edges.

(*c*) The cross section of the ice built up on the leading edges (see Fig. 6—drawing of piece recovered from strut).

(*d*) Ice crystals accumulated on underside of top planes along the length of the chord; the density of this ice gave the surface of the plane the appearance of a sugar loaf or rough sandpaper. It was, of course, impossible to see the bottom surface of the bottom planes.

" The anti-freezing solution was then turned on for exactly 30 minutes. At the conclusion of five minutes the two large accumulations on the leading edges of port bottom plane and port side of tail plane referred to above, broke away. After 30 minutes, with the exception of a few isolated crystals only, slight frosting could be observed on the leading edges of the port bottom plane and tail plane.

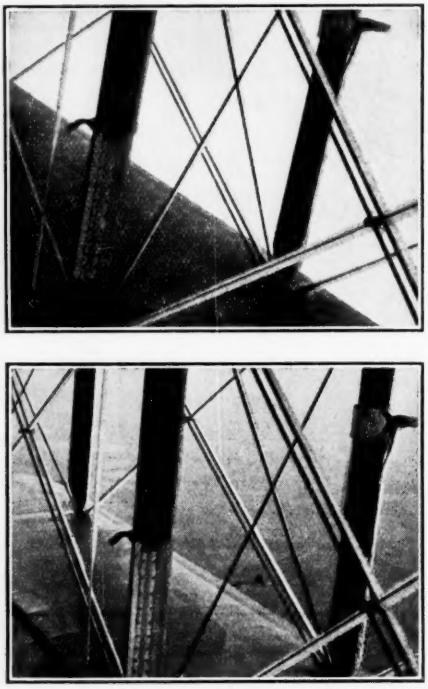

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FIG. 7.

Gordon with wing anticers under ice forming conditions.

" Throughout this period ice continued to build up on the interplane struts and wires, but the leading edges of the starboard bottom plane and fin appeared absolutely clear, even of frosting."

The consumption of ethylene glycol was at the rate of 1.7 pints per hour.

Photographs Obtained in Flight

Figs. 7 and 8 are reproductions of photographs, taken from a film shown at the conclusion of the lecture, illustrating the action of the anticer under ice forming conditions. Fig. 7 shows the leading edge of the lower wing of the Gordon aeroplane fitted with the anticer and clear of ice except for a small patch at A in the lower photograph. Fig. 8 enables a comparison to be made between the behaviour under ice forming conditions of a tail plane fitted with anticer (port side) and the normal surface (starboard side). The port side is free from ice except for a small patch in the neighbourhood of the stub tube. The fin to which an anti-icer is fitted is also free from ice.

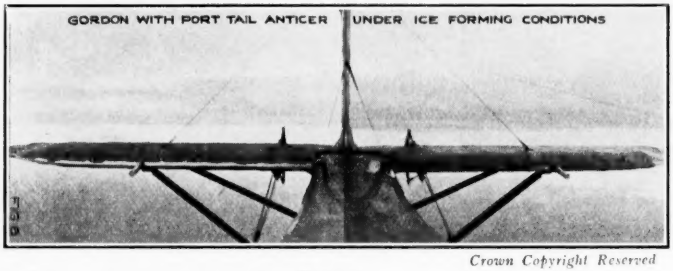

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FIG. 8.

Advantages of the Chemical Method

The advantages of this method of prevention are:—

(*a*) *Lightness.*—The nose fitting weighs 0.12lbs. per foot run for a R.A.F. 26 section. For the Hart aeroplane this amounts to about 9lbs. One gallon of liquid, allowing two pints for initial saturation and six pints to cover two hours' flying under ice forming conditions, weighs 12lbs. Provision must be made for container, connections and flow meter, say 8lbs., giving a total of about 29lbs. in all. The container and its liquid need only be carried when there is a likelihood of meeting ice forming conditions.

(*b*) The fitting is easy to instal on existing aircraft and may be carried out without any appreciable effect on the aerodynamic characteristics of the wing sections.

The Airscrew

Pilots, flying through ice forming conditions, frequently find themselves in danger of being hit by lumps of ice flung off the airscrew. At any particular point on the airscrew the centrifugal force on the ice varies as the cube of the dimensions and the adhesion as the square, consequently a certain critical thickness of ice must be reached when the adhesion is overcome. Centrifugal force, also, tends to produce a distribution of ice accreting heavily on the boss and at the root, tapering off towards the tip.

Heat generated in the blades in overcoming viscuous drag also plays a part in determining the distribution of ice. The temperature reached by the blade increases progressively from root to tip, but, as far as the author is aware, no exact measurements of the heating of airscrew blades have been made. Rough

measurements made at the Royal Aircraft Establishment, based on observations of indicating bodies of low melting point fused on the blades, show that at the tip of a Fairey Reed airscrew, rotating at 1,100 r.p.m. and absorbing 500 h.p., a rise of temperature above the airstream of 14°C. is obtained. Midway between the root and tip the temperature rise is 8°C. In temperature regions, therefore, where ice formation is more severe, ice deposits are confined to the central parts of the airscrew where the loss of thrust due to change of section on icing is less serious. A further loss of thrust, however, may arise indirectly. Ice tends to be dislodged unequally from the blades, leading to a large out of balance and excessive vibration, which the pilot is obliged to meet by throttling back. Provided the wings and tail plane are efficiently protected from ice accretion it is probable that throttling back may enable the pilot, in many cases, to continue

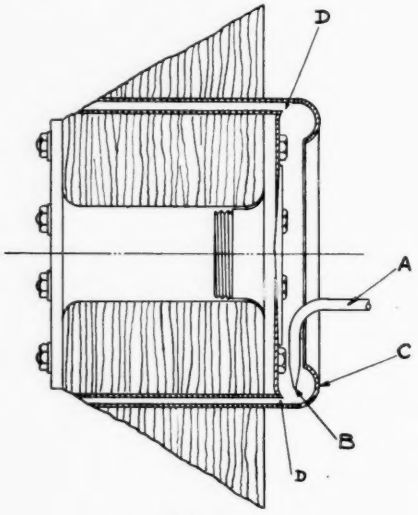

FIG. 9.
Diagram of anticer modifications of airscrew boss.

flight without undue anxiety, but there is little doubt that protection for the airscrew within a certain radius should be provided. In the case of a 10ft. diameter airscrew running normally at 1,500 r.p.m., it is considered that protection is required for about half the radius.

The Chemical Method Applied to the Airscrew.

The method outlined above can be applied to the airscrew with modifications. Wet leather is stretched tightly over and moulded to the shape of the boss and the part of the blade requiring protection. After drying in position it is firmly cemented down except at the leading edge. Ethylene glycol is led in under the leather by a short pipe at the root, is distributed outwards by centrifugal force, percolating through the porous leather along the chord by capillary flow. The method of achieving this is shown in Fig. 9. Liquid is supplied under pressure through the stationary pipe A and discharged through the nozzle B into a banjo C bolted to the rear of the airscrew boss. Centrifugal force discharges the liquid, through pipes D at the leading edges near the root. The pipe A is connected to the main supply of liquid under pressure and the dimen-

sions of the nozzle are adjusted to provide the required flow. Fig. 10 shows a wooden airscrew treated in this manner.

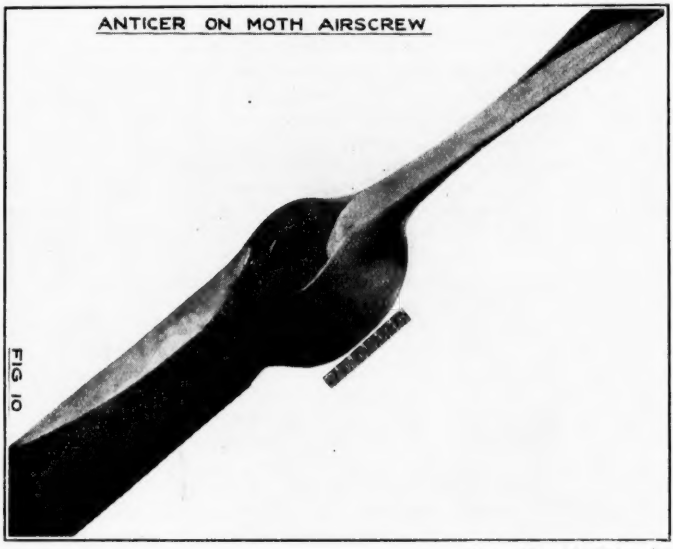

FIG 10

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Acknowledgment

Throughout these investigations the author has had the advantage of close collaboration with his colleague Dr. J. E. Ramsbottom, to whom much of the credit of the above work is due.

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8. Ice formation on aircraft and its prevention. J. Frank. Inst., 210, 5, Nov. 1930. M. Scott.
9. The prevention of the ice hazard on airplanes. W. G. Geer and M. Scott.
10. Refrigerated wind tunnel tests on surface coatings for preventing ice formation. N.A.C.A. Technical Note No. 339. M. Knight and W. C. Clay.

Following the presentation of the paper, Mr. Lockspeiser exhibited a cinematograph film, illustrating the accretion of ice on the wires and struts of the main planes, and on the tailplanes, fin, etc., of aircraft during flight, and the almost complete absence of ice on leading edges where the anticer was fitted.

Although a certain amount of ice was picked up from time to time on the protected surfaces, it cleared away rapidly.

He also demonstrated on models of thick and thin wing sections the operation of the anticer.

Discussion

The Chairman: There were two important qualities which the ideal anticer should possess. In the first place, the outward form of the aeroplane should be left entirely unaffected, if possible, by the arrangements fitted; secondly, it should be capable of remaining dormant for weeks or perhaps months at a time and yet be ready to function correctly whenever the occasion arose. The first requirement appeared to be met by Mr. Lockspeiser's form of anticer; with regard to the second, he asked whether the leather used in the experiments retained its qualities for a long time or whether it would perish or become hard under the influence of the ethylene glycol; and whether the tests had extended over a sufficiently long period to prove that it could be trusted to function with certainty after having remained dormant for a considerable time.

Major R. H. Mayo (*Fellow*): He welcomed the opportunity to congratulate Mr. Lockspeiser on his extremely interesting and illuminating paper, and to thank him and his collaborator, Dr. Ramsbottom, for the great work they had done. Not only had Mr. Lockspeiser stated the problem in a much clearer way than it had ever been stated before, but he had also put forward a simple, straightforward and practical solution of the problem. Major Mayo's view was that the simplicity of the invention would be the basis of its future success; it seemed to have very great advantages in regard to simplicity as compared with either the thermal or the mechanical method of dealing with the prevention of ice accretion. One felt that in the anticer described there was very little to go wrong and that it ought to fulfill the requirement mentioned by the Chairman, that it should be able to perform its function with certainty when required, after having been dormant for a long time.

By reason of his association with practical air transport, Major Mayo was able to appreciate very thoroughly the extreme importance of the problem of preventing ice accretion. It was remarkable that the problem should have cropped up seriously only within the last two or three years. During his early years in the aviation world nobody experienced this ice formation on aircraft, and he believed it was true to say that only very recently had it become such a formidable and prominent problem. One might be led to think that meteorological conditions had taken a turn for the worse; but it must be admitted that that was not the case. The real reason, of course, was that there had been an enormous increase in the amount of cloud flying and bad weather flying generally. Nowadays the great air transport companies were undertaking flights during winter weather in conditions in which regular flying would not have been contemplated a few years ago; services started off in bad conditions and had to deal with worse conditions as they arose en route. It was often said that the way in which to avoid ice formation on aircraft was to avoid flying in ice-forming clouds. Anyone closely concerned with air transport, however, would know that that was quite impossible; once a pilot had started a journey he might find it impossible to avoid flying through clouds which resulted in the formation of ice within a few seconds, of exactly the kind which Mr. Lockspeiser had shown. It was no exaggeration to say that under some of the conditions experienced in Central Europe, from $2\frac{1}{2}$ to 3 inches of ice might form well within the period of a minute, or even in considerably less time than a minute.

The circumstance which had brought about the great increase of cloud flying was the advent of blind-flying instruments, which had rendered such flying possible; and the irony of the situation was that under ice-forming conditions the first things to go astray were the blind-flying instruments. At the same

time, there was loss of lift and very likely loss of control. His colleagues and he had certainly arrived at the conclusion that there was no way of avoiding those conditions, and no reasonable prospect of providing an instrument or combination of instruments to indicate the probable presence of such conditions. Instruments can be provided to indicate the humidity and temperature outside a cloud, but the combination of those two instruments would not indicate the presence of ice-forming conditions inside the cloud. So that the only way of dealing with the problem was to provide means of preventing the ice formation. It was realised, of course, that it was most important first to prevent ice forming on the wing surfaces, tail surfaces, control surfaces and perhaps the propeller; the other things could be dealt with later. He hoped that when the anticer was further developed the principle would at least be tried out in connection with the instruments—the Venturis of the blind-flying instruments and the Pitot head of the air-speed indicator, and so on. There seemed distinct possibilities that the chemical method might be so applied.

Imperial Airways, Ltd., had been so impressed by the simplicity and straightforwardness of the anticer that they had made arrangements already for it to be tried out on one or more of their aircraft under service conditions, and if the anticipated success were achieved there was very little doubt that there would be a general application of the method to aircraft which were liable to encounter ice-forming conditions.

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Finally, he added a word of congratulation to the Dunlop Rubber Company, through whose enterprise the anticer had become commercially available.

Mr. R. H. Woodall (*Associate Member*): He congratulated Mr. Lockspeiser upon his development of the anticer. The speaker showed a film illustrating the fitting and operation of a wing overshoe having three inflatable inner tubes, as mentioned in the section of the paper dealing with the mechanical method of preventing ice formation. The overshoe was developed by the Goodrich Rubber Company, of America, in co-operation with the Elipse Aviation Corporation. Overshoes of this type were fitted to wings, tailplanes and fins of aircraft. The film showed the installation on the aeroplane "Miss Silvertown," described as the Company's "laboratory of the air," the overshoes being fitted very speedily by means of zip fasteners. When ice formed on the overshoes, the inner tubes were inflated and deflated alternately by means of a pump controlled from the cockpit, and the film showed the breaking of the ice by the movement of the inner tubes, and the pieces of ice being blown away from the surfaces of the overshoes.

The film illustrated also the use of the overshoes on trans-continental mail planes in America, and the de-icing equipment on propeller blades.

The rubber used for the overshoes is specially processed.

Air for the inflation of the inner tubes is obtained from the pressure side of a vacuum pump, the use of which is becoming more popular on aircraft for operating normal aircraft navigating instruments.

A rotary distributor valve driven either from a dual tachometer drive on the engine, or by a separate electric motor, controls the period of inflation and deflation of the tubes, a complete cycle taking 40 to 60 seconds.

Air Commodore R. H. Verney (*Associate Fellow*): How would Mr. Lockspeiser apply his anticer device to a long span wing? He suggested that there might be some difficulty in securing an even flow of the liquid along the

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Air Commodore R. H. Verney (*Associate Fellow*): How would Mr. Lockspeiser apply his anticer device to a long span wing? He suggested that there might be some difficulty in securing an even flow of the liquid along the

length of the wing. He was also doubtful whether the leather surface would withstand severe conditions. Some form of metal leading edge would probably be more durable, but he imagined there would be difficulties in applying the device to it.

Mr. C. J. STEWART (*Fellow*): Although Mr. Lockspeiser had been most lucid and thorough in his explanation of the device, he had omitted to mention the tremendous amount of difficult work accomplished by himself and Dr. Ramsbottom in its development. Without Dr. Ramsbottom's knowledge of fabrics, leathers and dopes, and Mr. Lockspeiser's persistence and determination in attacking the problem, they would not have had the device in anything like the form in which it was presented. It appeared almost too simple for words.

Reference had been made by the Chairman to rough and ready methods. The methods used during the early part of the work were rough, but perhaps not so ready. The foul mixture of soap and other substances was applied to surfaces by means of knives or trowels; it had worked for a time and was thought to be good, and the service was pressing for something which would enable machines to fly in cloud. The mixture was sent, in all good faith, to a squadron, and it was applied to the machines at night, ready for a trial next morning. But the wet air attacked it during the night, and in the morning it was found lying in a rather sad mess on the hangar floor underneath the machines.

The work had been started, of course, as the result of pressure from the Air Ministry. As a foundation, all the American reports were studied, a vast amount of work having been done on the subject in America. But it was felt that there was nothing in the reports which would help the evolution of a device which would prevent ice formation and which would not at the same time reduce the lift of a machine. All sorts of methods were mentioned, including the hot pipe method.

It was fair to say that the solution arrived at at Farnborough was the result of very considerable work. It might seem a very simple matter to pass liquid through a leather surface; and it was eventually. But when one first tried it one would probably find that the leather surface became rather like that of an old boot. The leather must be taut when fitted, and after it had been wetted it must remain taut. So far as could be seen from the experiments at Farnborough, when the right leather was chosen there seemed to be no great likelihood that the surface would perish. The device had not yet been applied to a very big span, but no great difficulty was anticipated in that regard.

The simplicity of the device revealed the work of the true scientist. The principle was merely to spoil the grip of the ice on the leather, and to leave it to nature to clear away the ice. That was why the method was being developed with considerable energy instead of the mechanical method, which undoubtedly did very good work, and it was hoped that the device developed at Farnborough would do equally good work. The way in which the latter was applied to the leading edge without in any way spoiling the action of the air on the wing was perhaps one of its outstanding qualities; in view of modern flying conditions, the staff at Farnborough would not develop anything which was likely to spoil the leading edge of the wing.

There were objections to taking heat to the wing surfaces and using the wing as a cooler, and one hesitated to send exhaust heat down to the tailplane surfaces. Mr. Stewart did not think it would be at all easy to do so; and it might not be very profitable, having regard to the little heat that could be taken there. Again, one was not very keen about throwing too much heat away, if this could be avoided, for there were plenty of uses for heat. If, after extensive flight trials, the anticer turned out to be as successful as it promised, it would be a more direct and a far better and simpler method from all points of view than trying to use heat.

The CHAIRMAN: He was glad that speakers had emphasised the great amount of scientific work which had been devoted to the perfection of the anticer as a practical means of preventing ice formation. Like many other things, when it was developed it seemed to be very simple; but it would not have worked at all had not Mr. Lockspeiser and his colleagues devoted very great care to the preparatory work.

REPLY TO DISCUSSION

Although he could not guarantee the leather, he believed that organic liquids such as glycerine, and allied substances such as ethylene glycol, were very good for leather; and he doubted whether the leather would dry out during the winter, owing to the very low rate of evaporation. In the course of his experiments he had not seen the leather dry out during the whole of last winter—and he supposed that in the ordinary course of events, if the device were fitted to aeroplanes, there would be inspections at least monthly and the apparatus would be flooded on those occasions to ensure that it was working properly. So long as the leather had ethylene glycol or glycerine in it—and it was the intention to use a mixture to which some glycerine was added—the life of the leather should be ensured.

Replying to Air Commodore Verney, he said that as the device was used at the moment the conditions were substantially those of hydrostatic flow. The flow through the tubes was so low that the liquid was discharged through the holes at sensibly uniform pressure. At the start there was a pressure of about 30 or 40lbs. to get the liquid out, and the pressure drop at the end of the Hart or Gordon wing was not more than 2lbs. So that sensibly there was hydrostatic pressure over the whole system, and that could still be achieved within limits if more flow were required, by placing similar pipes in parallel.

Dealing with the problem of the large span, and considering the thick-wing monoplane, he said that wings of this kind would probably be fed in sections. If the engine were mounted on the wing one would protect the part of the wing between the fuselage and the engine with one supply and then protect the part of the wing between the engine and the tip with another, so dividing the wing into two parts. If there were difficulty, there was no reason why there should not be a feed from both ends.

The vote of thanks to Mr. Lockspeiser, proposed by the Chairman, was heartily accorded, and the meeting closed.

ABSTRACTS AND NOTICES
FROM THE
SCIENTIFIC AND TECHNICAL PRESS

PART I.—PHYSICS AND ENGINEERING SCIENCE

Issued by the

Directorates of Scientific Research and Technical Development, Air Ministry

(*Prepared by R.T.P.*)

No. 35. SEPTEMBER, 1935

LIST OF ABBREVIATIONS OF TITLES OF JOURNALS.

Aeron. Eng.	Aeronautical Engineering.
Airc. Eng.	Aircraft Engineering.
Ann. d. Phys.	Annalen der Physik.
Army Ord.	Army Ordinance.
Autom. Absts.	Automotive Abstracts.
Autom. Tech. Zeit.	Automobiltechnische Zeitschrift.
Autom. Eng.	Automobile Engineer.
Autom. Ind.	Automotive Industries.
Bell Tele.	Bell Telephone Laboratory.
Bur. Stan. J. Res.	Bureau of Standards (U.S.A.) Journal of Research.
Chem. Absts.	Chemical Abstracts.
Chem. and Ind.	Chemistry and Industry.
D.M.Z.	Deutsche Motor-Zeitschrift
F.G.I.	Forschung auf dem Gebiete des Ingenieurwesens.
Fuel.	Fuel in Science and Practice.
H.F. Technik.	Hochfrequenztechnik und Electroakustik.
Ind. and Eng. Chem.	Industrial and Engineering Chemistry.
J. Aer. Sci.	Journal of the Aeronautical Sciences.
J.R. Aer. Soc.	Journal of Royal Aeronautical Society.
J. Frank. Inst.	Journal of Franklin Institute.
J. Sci. Inst.	Journal of Scientific Instruments.
L'Aéron.	L'Aéronautique.
L.F.F.	Luftfahrtforschung.
N.A.C.A.	National Advisory Committee for Aeronautics (U.S.A.)
Phil. Mag.	Philosophical Magazine.
Phys. Zeit.	Physikalische Zeitschrift.
Proc. Inst. Rad. Eng.	Proceedings of the Institute of Radio Engineers.
Proc. Roy. Soc.	Proceedings of Royal Society.
Pub. Sc. et Tech.	Publications Scientifiques et Techniques du Ministère de l'Air.
Riv. Aeron.	Rivista Aeronautica.
S.A.E. Jrnl.	Society of Automotive Engineers Journal.
Sci. Am.	Scientific American.
Tech. Aéron.	La Technique Aéronautique.
Trans. A.S.M.E.	Transactions of the American Society of Mechanical Engineers.

W.R.H.	Werft-Reederei-Hafen.
Z.A.M.M.	Zeitschrift für Angewandte Mathematik und Mechanik
Z.F.M.	Zeitschrift für Flugtechnik und Motorluftschiffahrt.
Z. Instrum.	Zeitschrift für Instrumentenkunde.
Z. Metallk.	Zeitschrift für Metallkunde.
Z.V.D.I.	Zeitschrift für Vereines Deutscher Ingenieure.

Aircraft—Design, Performance, etc.

Performance of Modern Light Aeroplane. (W. Pleines, Z.V.D.I., Vol. 79, No. 3, 19/1/35, pp. 57-64.) (5.10/30501 Germany.)

A detailed comparison is made of the seven types of aeroplane which took part in the European circuit of 1934. The rapid progress of the past ten years is slowing down as the possible technical improvements become more fully exploited.

Glen L. Martin Clipper No. 7. (Sci. Am., Vol. 152, No. 3, March, 1935, pp. 149-150.) (5.14/30502 U.S.A.)

A photograph shows the general appearance of the high wing monoplane flying boat with four 800 h.p. Wasps mounted on the leading edge. The estimated performance is given for a total flying weight of 51,000lb.

Wasted Effort in the Pacific. (*Re* Trans-Oceanic Flights.) (J. Am. Soc. of Naval Engineers, Vol. 47, No. 1, Feb., 1935, pp. 157-158.) (5.14/30503 U.S.A.)

According to report twenty-four naval and ten army aircraft have been searching for the aviator C. T. Ulm and his companion, missing in flight from California to Hawaii.

The French Government prohibit flights across the Sahara until a deposit is made to cover search by the French Air Force in case of accident. It is suggested that the U.S. Government and shipping firms should announce that no search will be made for missing trans-oceanic flyers.

Technical Points from the Australian Flight. (Luftwissen, Vol. 1, No. 11, 15/11/34, pp. 312-314.) (5.14/30504 Germany.)

A technical appreciation is given of the conditions of the flight and the performance of the principal competitors.

Three references.

Conference on Aeronautical Research. (Luftwissen, Vol. 1, No. 11, 15/11/34, pp. 299-309.) (5.14/30505 Germany.)

The Annual Meeting of the D.V.L. has hitherto been the most important occasion of the year. The great expansion of German aeronautics has given comparable importance to the meeting of the "V.L.F." (Association for Aeronautical Research). Its membership consists of recognised experts and authorities and its most important function is to bring about exchange of information and experience throughout Germany by papers and visits. It has also promoted research work. Summaries of the following papers are printed:—

Daeves.—Collaboration of research and industry.

Grimm.—Projecting and working out a research programme in a chemical works.

Seewald.—Organisation of aeronautical research in other countries.

v. Schlippe.—Influence of power plant characteristics on aeroplane design.

Bruckmann.—Influence of aeroplane requirements on engine design.

Ebert.—Influence of aeroplane and power plant on airscrew design.
Lürenbaum.—The engine as a source of vibrations.
Damm.—Accessibility and maintenance of engines.
Eisenlohr.—Engine mountings and engine tests.
Neugebauer.—Problem of distant drive.
Lorenz.—Cooling of aero engines.

Formulæ and Methods of Calculation for Sheet and Shell Construction of Aircraft. (O. S. Heck and H. Ebner, L.F.F., Vol. 11, No. 8, 6/2/35, pp. 211-222. D.V.L. Report 34/01.) (5.152/30506 Germany.)

Collected formulæ are drawn from numerous sources under the following headings:—

(1) Isotropic rectangular plates under end pressure—twenty-three references.
(2) Strength of rectangular plates with stiffeners, under pressure—ten references.
(3) Rectangular plates with stiffeners, under shear—seven references.
(4) Isotropic circular cylindrical shell segments under axial pressure—three references.
(5) Circular cylindrical shell segments with stiffeners, under pressure—four references.
(6) Strength of complete circular cylindrical shells under axial load—nineteen references.
(7) Complete circular cylindrical shells under bending—six references.
(8) Complete circular cylindrical shells under torsion—seven references.

Translated by A.I. (T.). Translation No. 264.

Constructional Details of (Non-German) Smooth Shell-Built Aeroplane Bodies. (H. Winter and E. Hoffmann, L.F.F., Vol. 11, No. 8, 6/2/35, pp. 235-240. D.V.L. Report 34/02.) (5.152/30507 Germany.)

Examples are collected from the non-German technical press. Four photographs, eight perspective sketches and some section sketches are reproduced. Specifications of U.S.A. riveting practice are given in a table.

Three references.

The Power Plant as a Source of Vibrations. (K. Lürenbaum, L.F.F., Vol. 11, No. 7, 14/1/35, pp. 200-201.) (5.17/30508 Germany.)

A brief descriptive account is given of vibration troubles and methods of restricting them.

Vibrations of Coupled Systems. (W. Quade, Ing. Arch., Vol. 6, No. 1, Feb., 1935, pp. 15-34.) (5.17/30509 Germany.)

After some generalities on transformation of co-ordinates detailed consideration is restricted to two degrees of freedom. The types of motion with two degrees of freedom are classified according to the nature of the roots of the determinantal equation. Five diagrams of elastic systems illustrate different types of coupling, corresponding to different types of roots.

Eight references.

Variation of Maximum Lift Coefficient with Turbulence and Reynolds Number. (C. B. Millikan, Trans. A.S.M.E., Vol. 56, No. 11, Nov., 1934, pp. 815-818.) (5.20/30510 U.S.A.)

Previous tests with N.A.C.A. 2412 profile in turbulent air led to certain conclusions, particularly that the boundary layer branched from the surface near

the trailing edge, but at stalling incidence the branching point ran back to the neighbourhood of the leading edge. Tests on the effect of tail splitting flaps and tests with other wing profiles show such irregularities that the assumption can have no general application.

Test data are given graphically.

Five references.

Theoretical Investigation of Maximum Lift Coefficient. (T. v. Kármán and C. B. Millikan, J. of Applied Mechanics, Vol. 2, No. 1, March, 1935, pp. A-21—A-27.) (5.20/30511 U.S.A.)

Measurements with an N.A.C.A. 2412 aerofoil indicated a correlation between turbulence and maximum lift coefficient. An explanation is constructed in terms of boundary layer phenomena, particularly with regard to the point of transition from laminar to turbulent flow and the branching point at which the stream is diverted from the upper surface.

Anomalies are recorded and the difficulty of extended application is recognised.

Induced Resistance of Wings with Small Aspect Ratio. (Schilhansl, L.F.F., Vol. 12, No. 1, 28/3/35, pp. 55-56.) (5.20/30512 Germany.)

The field of velocity near the wing tips was explored by small streamers. In certain positions, in the neighbourhood of the wing tips, the streamers described conical gyrations, from which it was possible to determine the axes of the two twirling eddies into which the vortex sheets had rolled up. The distance between the eddy axes was greater than the wing span by an amount which increases with decreasing aspect ratio from zero at 6 : 1 to 25 per cent. of the span at 1 : 2. The induced velocity calculated in accordance with this result accounts for certain variations in the induced velocity from the value calculated by the usual theory.

Influence of Section on Wing Characteristics. (F. Ursinus, Flugsport, Vol. 27, No. 1, 9/1/35, pp. 33-36.) (5.20/30513 Germany.)

An empirical algebraic expression is given for a profile with thickness equal to 20 per cent. of chord and maximum thickness at about one-third chord.

Investigations of the Downward Component of Velocity Behind Wings with Rectangular and Elliptic Plan Form. (H. Muttray, L.F.F., Vol. 12, No. 1, 28/3/35, pp. 28-37.) (5.22/30514 Germany.)

The belt of vorticity streaming backwards from the wing rolls up into two roughly circular tubes of vorticity.

The calculation of the velocity field due to the vorticity distribution may be carried out mathematically either on the assumption that the rolling up is complete at the wing, or on the assumption that no rolling up takes place for a large distance behind the wing. The former assumption is a better approximation for the rectangular form, the latter for elliptical forms.

The usual theoretical considerations are recapitulated and results of computations are shown graphically.

Experimental results are plotted for comparison with different incidences and different stations behind the wings.

Eight references.

Torsional Vibration of Cantilever Monoplane Wings. (A. Bellomo, L'Aerotecnica, Vol. 15, No. 3, March, 1935, pp. 276-298.) (5.24/30515 Italy.)

Aerodynamical characteristics are taken from N.A.C.A. Report No. 460.

The equations of motion are formed in the usual way and numerical applications are worked out in detail.

Effect of Trailing Edge Flaps. (G. A. Allward, Aero Digest, Vol. 26, No. 3, March, 1935, pp. 24-26.) (5.30/30516 U.S.A.)

Expressions for flap moments are determined in terms of lift coefficient and moment given graphically as functions of relative incidence and total effective incidence of wing and flap.

Airscrews

Propeller Cavitation Studies. (C. O. Kell, J. Am. Soc. of Naval Engineers, Vol. 47, No. 1, Feb., 1935, pp. 123-136.) (5.60/30517 U.S.A.)

Reference is made to observations of full-scale phenomena by a window in the hull of a destroyer and to stroboscopic observation in the model channel.

Face cavitation is described and appears to be due to bad entry at the leading edge near the root. It is observed only at high slip ratios and does not affect the performance. It is unknown in blades designed on modern lines in accordance with aerodynamic theory, a result of some importance.

The rest of the paper is on the usual lines and gives interesting independent observations. In the discussion Hunsaker refers to an experimental installation at the Massachusetts Institute of Technology for the visual study of cavitation. Riabouchinsky refers to numerical solutions of the equation of flow round a cylinder with cavitation.

Sixteen references.

Influence of Pitching on Resistance of Ships and Efficiency of Screws. (G. Kempf, W.R.H., Vol. 16, No. 1, 1/1/35, pp. 1-4.) (5.60/30518 Germany.)

Graphical records are given of variations in shaft load as functions of speed in calm water and with waves of 80 m. and 120 m. in length. The screw efficiencies under these conditions are given as 64, 55.5 and 36.5 per cent.

Four references.

Propeller Vibrations and the Effect of Centrifugal Force. (T. Theodorsen, N.A.C.A. Tech. Note No. 516, 1935.) (5.63/30519 U.S.A.)

The frequency of transverse vibration of a full-scale propeller is first investigated with the propeller stationary, the engine crankshaft being subjected to periodic impulses.

The effect of centrifugal force is very marked, the relationship between stationary and revolving propeller frequencies being given by the relation

$$f = \sqrt{(f_o^2 + CN^2)}$$

when f = frequency of revolving propeller (vibration/minute).
f_o = frequency of stationary propeller (vibration/minute).
N = r.p.m.
C = a constant depending on mode of vibration.

(C increases rapidly with order of vibration, ranging from 1.7 for fundamental to 12 for third order.)

As an example, a stationary frequency (third order) 10,000/minute is raised nearly 50 per cent. if propeller rotates at 3,000 r.p.m.

The author has devised a neat experimental method of determining the effect of centrifugal force by subjecting a model propeller or reduced stiffness to slow speed rotation. The blades of the model are enclosed in tubes and resonance is detected by contact during rotation. From this model experiment the effect on the full-scale propeller can be estimated.

Seven references.

Systematic Measurements on Variable Pitch Airscrews. (H. B. Helmbold, L.F.F., Vol. 12, No. 1, 28/3/35, pp. 4-9.) (5.64/30520 Germany.)

Comprehensive numerical data are given for the construction of a blade with constant geometrical pitch for no lift incidence of each element. With change of Reynolds number the no lift incidence changes slightly from section to section.

The blade width is given by a formula which contains a correction for compressibility and is strictly applicable only for a particular combination of angular and axial velocities.

The aerodynamic theory for variable incidence is developed along usual lines with some modifications, particularly the introduction of empirical coefficients which are tabulated numerically for different values of the effective pitch and number of blades and also shown graphically.

Measurements were carried out and pitch, thrust coefficient, torque coefficient and efficiency are tabulated numerically and shown graphically for a range of pitch settings.

The observed values are compared with the values calculated from the semi-empirical equations and show satisfactory agreement until stalling is approached.

Six references.

Design and Construction of Variable Pitch Airscrews. (K. Otto and S. Hesse, Luftwissen, Vol. 2, No. 1, Jan., 1935, pp. 6-11, and No. 2, Feb., 1935, pp. 35-40.) (5.658/30521 Germany.)

American design data are reproduced graphically. Elementary expressions are formed for required thrust at starting and in flight and numerical values of efficiency, engine horse-power and thrust horse-power are tabulated for steady flight and for climb at three different speeds, for fixed pitch, variable pitch and ideal airscrews. Starting data are tabulated for single and two-engine aircraft.

The performance of a two-engine commercial machine at sea level, at 2,100 metres and at 4,000 metres with ideal variable pitch and fixed pitch airscrews is tabulated separately. Substantial advantages are shown.

Eight references.

Instruments

Fluid Meter Nozzles. (B. O. Buckland, Trans. A.S.M.E., Vol. 56, No. 11, Nov., 1934, pp. 827-832.) (6.22/30522 U.S.A.)

Shape and dimensions of forty nozzles are given tabularly and section sketches show the position of static pressure orifices in the nozzle.

Test results are given graphically and non-dimensional coefficients from 22 calibration curves plotted against Reynolds number lie with moderate scattering about unicursal curve.

Calibration of a " Normdüse " shows a sharp dip in the characteristic curve, corresponding to change of flow type at a certain value of Reynolds number.

Six references.

Intake Orifices for Testing Exhaust Fans. (N. C. Ebaugh and R. Whitfield, Trans. A.S.M.E., Vol. 56, No. 56, Dec., 1934, pp. 903-911.) (6.22/30523 U.S.A.)

The installation of fan, 23in. diameter pipe orifice, and measuring instruments is shown by photographs and sketches.

The configuration of mean flow is shown diagrammatically with a well defined vena contracta surrounded by an eddy region, marked by a pressure drop. This is followed by expansion of the effective jet to the point where it fills the pipe, with maximum recovery of pressure.

Calibration characteristics of six orifices, with diameters from 20 to 100 per cent. of the pipe, are tabulated and a scheme of tests by calibrated orifices is proposed.

Twenty-one references.

Throttle Plate for the Measurement of Oscillating Gas Streams. (S. Erk, Z.V.D.I., Vol. 79, No. 3, 19/1/35, p. 77.) (6.22/30524 Germany.)

The mounting and pressure measurements follow V.D.I. standard practice. The throttle plate recommended by Maekawa (Japan) has rounded edges and a thickness $d/3$, where d=diameter of plate opening. The flow coefficient is constant (0.835) in the range of Reynolds number from 14,000 to 100,000 for the ratio (d/D)=0.4, where D=diameter of tube containing throttle.

Hydraulic Current Meters. (F. A. Nagler, Trans. A.S.M.E., Vol. 57, No. 2, Feb., 1935, pp. 59-67.) (6.22/30525 U.S.A.)

Different types of water screw mountings are shown in eight photographs.

Examples of velocity distribution across channels are shown in over twenty contour charts. Difficulties of accurate calibration are discussed and the effect of turbulence in producing variation in velocity and direction are considered briefly.

Casual measurements of weir discharge gave errors of 40 per cent., but careful reduction of properly distributed observations reduced the maximum variation to less than 5 per cent.

Twenty-four references.

Note on Surface Tension Effect in Viscometers. (W. Linke, Phys. Zeit., Vol. 36, No. 2, 15/1/35, p. 45.) (6.225/30526 Germany.)

Discrepancies in viscometer measurements are explained in terms of surface tension effects.

Two references.

The Torsion Balance as Micromanometer. (H. Reichardt, Z. Instrum., No. 1, Jan., 1935, pp. 23-33.) (6.251/30527 Germany.)

A brief account is given of the defects of the pressure head manometer in reading small pressure differences.

A description is given of a direct pressure reading instrument. The pressure is transmitted to the head of a piston fitting a cylinder with a small clearance. The piston is mounted on a lever rotating about the axis of the torsion balance. The theory of the period and damping of the mechanism is discussed. The leakage flow past the piston is assumed to have parabolic distribution of velocity and the corresponding error is calculated from known expressions.

The mechanical details are shown in plan and elevation sketches. The range of measurement depends on the strength of the control spring, the sensitivity being about one thousandth of the whole range. With a fine spring measurement can be made over a range from 0 to 0.01 mm. of water, to 0.00001 mm. accuracy.

Pressure Recording Instruments for Rapid Pressure Variation. (S. Berg, Z.V.D.I., Vol. 78, No. 44, 3/11/34, pp. 1295-1296.) (6.251/30528 Germany.)

A short length of bent tubing of small volume (about 10 cubic millimetres) high period and great stiffness, carries a mirror at the closed end. Deflection proportional to the fluid pressure is recorded on a rotating drum at a distance.

The instrument is suitable for recording fuel pressure in the pipe line of injection engines.

One reference.

Electrical Speed Indicator for Ships, Submarines or Aeroplanes. (M. J. Breton, Comptes Rendus, Vol. 200, No. 10, 4/3/35, pp. 812-814.) (6.40/30529 France.)

The velocity head forces the fluid to flow through a pipe. The flow in a shunt pipe is warmed by an electric heater, the temperature rise being an inverse measure of velocity. By restricting the flow in the shunt pipe, the sensitivity can be maintained with small heating currents.

Junkers Aviation Log. (R. Preuschen, Luftwissen, Vol. 1, No. 11, 15/11/34, pp. 315-318.) (6.40/30530 Germany.)

The installation comprises a revolution counter, an air log depending on the calibration of r.p.m. of small airscrews against distance for different air speeds and a time-distance recording apparatus. Experience has shown the great advantage of logging air runs accurately. It is stated that the D.V.L. are progressing along similar lines. Five photographs show details of the installation.

One reference.

New Method of Measuring Ship Speed. (H. Hoppe and H. Lerbs, W.R.H., Vol. 16, No. 4, 15/2/35, pp. 53-56.) (6.40/30531 Germany.)

Examples are given of serious errors in logs actuated by towed screws. In the new method a dynamic pressure orifice in the stem and a static pressure orifice in each side, 5-10 m. aft, form a large scale pitot head. Three examples are given from a ship with the usual sharp stern and the " Bremen " and " Europa " with bulge sterns. Sketches show the bow profile, the water line section and the position of the orifices.

From the calibration curves the coefficient of velocity as a function of the square root of the pressure head appears to be practically constant for a given trim and to vary less than 1 per cent. for usual changes of trim. An experimental installation proved so satisfactory during the trial runs of the " Bremen " that a permanent installation was fitted in the " Europa." Details of the transmission and recording apparatus are given in a photograph and section sketches.

A graphical speed record during the run from Bremerhaven to Southampton is reproduced with critical notes on the effect of depth of water, rudder, etc., on the speed for given engine revolutions.

Three references.

Experiments on the Refraction of Ultra-Sound Waves. (W. Bez-Bardili, Phys. Zeit., Vol. 36, No. 1, 2/1/35, pp. 20-24.) (6.48/30532 Germany.)

Ultra-sound waves are generated by a quartz oscillator and propagated through a surrounding liquid medium. The periodic variations in density of the liquid form an optical grid, and illumination produces refraction patterns which indicate the position of the elastic waves. By interposing obstacles of various materials the refraction of the sound by the materials alters the wave pitch, from which the velocity is deduced.

Frequencies were used up to 18×10^6 cycles per second. The velocity of ultra-sound waves in Al and Cu is about 20 per cent. greater than for audible sound, in nickel about 50 per cent.

Six references.

Experiments with Copper Sub-Oxide Photocells. II. Hysteresis Phenomena. (W. Bulian, Phys. Zeit., Vol. 36, No. 1, 2/1/35, pp. 33-34.) (6.87/30533 Germany.)

Copper sub-oxide cells, with sputtered silver electrodes are entirely free from temperature effect from 10° to 80°C. The further condition of freedom from hysteresis is investigated and it is shown that after 150 hours' exposure the readings settle down to a nearly constant value of about 45 per cent. of the initial rating.

Five references.

Aircraft Flight

Mutual Influence of Power Plant, Aeroplane Performance and Airscrew Design. (H. Ebert, L.F.F., Vol. 11, No. 7, 14/1/35, pp. 197-199.) (7.15/30534 Germany.)

The elementary relations between power, r.p.m., flying speed, airscrew diameter and (fixed) pitch are discussed by illustrative numerical examples.

The theoretical advantages of variable airscrew pitch at high altitudes are shown graphically.

Mutual Influence of Power Plant and Aeroplane Structure. (B. v. Schlippe, L.F.F., Vol. 11, No. 7, 14/1/35, pp. 192-196.) (7.15/30535 Germany.)

The maximum cross section of the aeroplane body is largely determined by the type of engine. Outline sketches show side views of glycol-cooled, water-cooled and air-cooled engines, the effective area of resistance being given as 0.047, 0.15 and 0.1 respectively.

Suitable shaping of the airscrew blades near the hub may reduce air-cooled temperature by 20° to 40°C. Overheating of the cabin by the cooling air was experienced and remedied by closing the cowl above and letting the cooling air escape below.

For engines of comparatively low power air-cooled designs have lower head resistance, but for large powers the water-cooled engine, with radiator, becomes more compact.

A brief reference is made to shaft drive from central power plant. Ease of mounting and dismounting and accessibility are discussed from practical cases and illustrated by five photographs. The engine is considered as a source of forced vibrations and elementary physical relations are stated.

Airscrew Back-Stream and Longitudinal Stability. (H. Blenk, L.F.F., Vol. 11, No. 7, 14/1/35, pp. 202-206.) (7.20/30536 Germany.)

The equations of motion are formed in the usual way and a discussion is given of the modifications required to take into account the back-stream from the airscrew.

Comparisons are given graphically of model and full-scale experiments on Junkers A.35. Relations between airscrew thrust components and moments are given graphically as functions of incidence and polar curves are deduced.

Finally sixteen curves of elevator position are given for four positions of the C.G. and five throttle openings showing comparison between calculated and observed rudder angles. A scheme of research is suggested.

Nine references.

Air Conditions Close to Ground and Aeroplane Landings. (F. L. Thompson and others, N.A.C.A. Report No. 489, 1934.) (7.30/30537 U.S.A.)

A mast carried compound vanes indicating direction and intensity of wind at five heights, from 6ft. to 51ft. Thirty photographic records were taken at the

rate of one per second. The results, reduced to curves of wind velocity and direction as functions of time, are shown in seven figures. The mean wind speeds range from 8 to 16 m.p.h. Variation of wind speed is also shown as a function of height and an empirical equation giving a moderate fit is a parabola of the seventh degree.

A description is given of a recording theodolite camera, with calibrating controls, with which the flight path of aeroplanes was recorded during glide and landing. The results show graphically the wind velocity and aeroplane vertical velocity component as functions of height.

Seven references.

Siemens "Autopilot." (Luftwissen, Vol. 1, No. 11, 15/11/34, pp. 309-312.) (7.56/30538 Germany.)

The Siemens " autopilot " is an electric hydraulic installation regulated by suitable controls. The instruments required are substantially the same as for blind flying. A compass sets the course, a pressure head the speed, and a combination of gyro and pendulum the lateral control. These controls act separately or in groups on a relay which magnifies the control forces hydraulically. The damping is provided by gyrostat.

The settings of the controls for longitudinal and lateral trim in straight flight and in turns are described and diagrams of connections show full details and general arrangements of two installations.

Two photographs show the compact hydraulic relay in light alloy casing and the arrangement of the instrument board.

Effect of Mass Distribution and Control Setting on the Spinning of an Aeroplane. (N. F. Scudder, N.A.C.A. Report No. 484, 1934.) (7.62/30539 U.S.A.)

Previous investigations on the spinning of an aeroplane are continued with another aeroplane used for naval training. Extensive data are tabulated and the results are stated to be in accord with mathematical theory.

Five references.

Experiments with Suction Wings. (O. Schrenk, L.F.F., Vol. 12, No. 1, 28/3/35, pp. 10-27.) (7.72/30540 Germany.)

A thick profile (depth 40 per cent. of chord) had slots of different width pierced at different positions in the upper surface towards the trailing edge, through which air from the boundary layer was sucked into the interior of the wing. The volume of air removed per second is shown graphically as a function of suction pressure for eight combinations of slot width and position. The corresponding lift, polar and pressure distribution are shown graphically by faired curves.

Similar measurements with suction of the boundary layer were made on a thinner wing with trailing edge flaps of three different designs and the characteristics are shown by plotting observed values which lie on fairly smooth curves with moderate scattering.

Comparison between the two profiles (and a third profile without suction) is made in a brief numerical table showing the minimum resistance coefficient, maximum lift coefficient and maximum lift to minimum drag from which the thinner wing equipped with flaps appears to give a better all round characteristic than the thick profile.

No detailed analysis of the mass of figures in twenty-five numerical tables can be given, but there is a definite improvement in the calculated rate of climb, ceiling, starting and landing yaws with the second type of wing.

Seven references.

Engines—Thermodynamics

Advantages of the Terres Engine. (A. R. Leye, Science Absts. B, Vol. 38, No. 450, 25/6/35, p. 311.) (8.10/30541 Great Britain.)

This is a six-stroke engine, the normal expansion stroke of the four-stroke cycle being followed by a recompression stroke. Additional air is supplied before the final expansion stroke takes place. It is claimed that in this way there are no partly burnt exhaust products and the efficiency of the engine is improved.

Catalytic Combustion at High Temperatures. (W. Davies, Phil. Mag., Vol. 19, No. 126, Feb., 1935 (Supplmt.), pp. 309-325.) (8.13/30542 Great Britain.)

A wire of diameter 0.001in., heated to 1,250°C. in the most explosive mixture of CO and air does not cause ignition and gives no indication of combustion in the gas phase at its surface. At lower temperatures a gas phase reaction occurs readily. An explanation is given in terms of the Langmuir theory.

Eight references.

Engines—Design and Performance

Economic Engine Operation for Cruising Reliability. (E. T. Allen and W. B. Oswald, Aviation, Vol. 34, No. 3, March, 1935, pp. 89-92.) (8.225/30543 U.S.A.)

An engine failure is defined as engine trouble (apart from fuel system), causing a forced landing and a delay of ten minutes or more in schedule starting.

The rapid drop of reliability with increased cruising speed and power is shown in tables and graphs.

Two-Stroke Ship's Diesel Engine of 5,500 h.p. (G. Eichelberg, Z.V.D.I., Vol. 79, No. 5, 2/2/35, pp. 130-132.) (8.232/30544 Germany.)

The fuel injection pipe line is made intentionally long so that sufficient lag is obtained to enable the use of an injection cam which is symmetrical with regard to T.D.C. The engine can therefore be reversed in four seconds without having to touch the injection timing. The scavenge air is supplied by a piston compressor fitted with copper piston rings.

Re-design of Air Injection to Airless Injection (Ship's Diesel Engine). (K. Mohr, Z.V.D.I., Vol. 79, No. 5, 2/2/35, p. 144.) (8.25/30545 Germany.)

Messrs. Krupp have re-designed several air-injection engines to operate with direct fuel injection by Prof. Archaouloff's method. The old injection pump and cylinder head are retained. A small spring-loaded plunger operates, in tandem, a second plunger of smaller cross-section placed in the fuel line between the injection valve of the engine and the delivery of the original (low pressure) fuel pump.

The fuel is metered at low pressure as for air injection, compressed during the engine compression stroke and injected against the compression pressure. The timing depends on the hydraulic magnification and the spring load on plunger and injection valve. The injection system is water-cooled. Results are stated to be extremely satisfactory.

Aircraft Diesel-Power. (G. D. Angle, Aero Digest, Vol. 26, No. 3, March, 1935, pp. 30-34.) (8.26/30546 U.S.A.)

A fairly complete table is given of experimental aero Diesel engines showing rated h.p., weight/h.p., r.p.m., number and arrangement of cylinder and makers' names.

Four photographs are reproduced. No design details are given.

Engines—Design and Strength of Components

Current Practice in Lubrication of Oil Film Bearings. (H. A. S. Howarth, Trans. A.S.M.E., Vol. 56, No. 12, Dec., 1934, pp. 891-902.) (8.31/30547 U.S.A.)

Extensive data, supplied by makers of bearings are tabulated and exhibited graphically.

Practical rules for bearing design and selection of lubricant are given.

Sixteen references.

Design of Steam Turbine Disc Wheels. (I. Malkin, Trans. A.S.M.E., Vol. 56, No. 8, Aug., 1934, pp. 585-600.) (8.35/30548 U.S.A.)

Established formulæ are reduced to forms suitable for computation. Numerical tables of the functions involved are given. Two numerical examples are worked out.

Twelve references.

Side Leakage in Journal Bearings. (S. J. Needs, Trans. A.S.M.E., Vol. 56, No. 10, Oct., 1934, pp. 721-732.) (8.37/30549 U.S.A.)

Kingsbury devised a method of solving Reynolds general differential equation of motion of lubrication in a bearing by direct electrical measurements based on a mathematical physical analogy. In the present paper results obtained by this method are tabulated numerically and shown graphically. They include eccentricity and length of bearing, thickness of film, pressure distribution, flow of lubricant, side leakage and friction.

A numerical example is worked out for a 10-inch shaft carrying a total load of 25,000lb. at 1,500 r.p.m.

Ten references.

Rotor Balancing. (J. Bromberg, Trans. A.S.M.E., Vol. 56, No. 10, Oct., 1934, pp. 707-710.) (8.39/30550 U.S.A.)

A graphical method is given for determining the application of balancing masses from the out-of-balance forces and couples determined by experiment on a balancing machine. The object of the method is to eliminate trial and error adjustments.

Five references.

Dynamic Balancing in the Field. (E. L. Thearle, Trans. A.S.M.E., Vol. 56, No. 10, Oct., 1934, pp. 745-753.) (8.39/30551 U.S.A.)

A rod is fastened by an adaptor to the vibrating part, *e.g.*, a turbine generator bearing, and imposes vibration on a coil in a stationary magnetic field. A cam drive from the shaft makes and breaks the induced A.C. through alternate arcs of 180°. The D.C. micro-ammeter is connected in the circuit and by angular adjustment of the contact the current may be rectified to a maximum reading which is a measure of the amplitude, or to zero reading, giving the phase angle. Two such devices, one on each bearing, give sufficient data for determining the necessary balancing by a graphical process, of which a worked example is given.

There are twenty photographs and diagrams.

Engines—Cooling

Recent Advances in Heat Flow Research. (E. Schmidt, Z.V.D.I., Vol. 79, No. 3, 19/1/35, pp. 68-72.) (8.40/30552 Germany.)

The symposium of papers presented to the 10th Annual Meeting of the Sub-Committee for Heat Research covers a wide field. Specific heat and dissociation values of technical gases have been reviewed with the object of furnishing more reliable data for the thermodynamics of explosions.

In connection with steam research, recent developments render some of the theories of the late Prof. Callendar untenable. Throttle plate measurements of technical gases have now reached a high order of precision. If the gases contain suspended particles of water (in the form of fog) measurements are liable to errors of the order of 10 per cent.

The effect of roughness on pressure measurements in pipes has been further investigated by Schiller. The free convection of heat from square plates has been investigated with a quartz fibre anemometer.

Thermal Conduction Through Vapours. (S. W. Milverton, Proc. Roy. Soc., Vol. A. 150, No. 870, 1/6/35, pp. 287-308.) (8.40/30553 Great Britain.)

The precautions taken to prevent convection are of interest, in reference to the criterion for instability of layers of a gaseous layer heated from below.

Eleven references.

Calculation of Surface Temperatures. (S. Goldstein, Z.A.M.M., Vol. 14, No. 3, June, 1934, pp. 158-162.) (8.40/30554 Germany.)

In calculating the rate of cooling of bodies bounded by planes, cylinders and spheres, the function expressing the temperature field may be integrated in series.

For small values of time the operational method of Heaviside gives approximate expressions in terms of the error function and exponentials which give accurate values by easy computations, in the region where the corresponding series converge so slowly that the numerical computations become laborious and the number of significant figures obtainable becomes small.

Examples are given for plane circular cylinder and sphere, with numerical tables.

The Average and Local Rates of Heat Transfer from the Surface of a Hot Cylinder in a Transverse Stream of Fluid. (J. Small, Phil. Mag., Vol. 19, No. 125, Feb., 1935, pp. 251-260.) (8.40/30555 Great Britain.)

The average rate of heat transfer was obtained from the total heat input in watts. The local rate was estimated from the readings of a thermocouple imbedded in the surface. The coefficient of heat transfer reaches a minimum value on the diameter at right angles to the stream. On the diameter parallel to the stream the coefficient reaches about three times the minimum value.

Eight references.

Best Forms of Grate Bars. (J. Bock, F.G.I., Vol. 6, No. 1, Jan./Feb., 1935, pp. 23-32.) (8.40/30556 Germany.)

Simplified problems of flow of heat in bars receive elaborate mathematical treatment. The flow of air through the bars and of mixed gases in the furnace are discussed empirically and numerous curves of velocity distribution are reproduced.

The combined problem leads to elaborate families of curves giving total flow of heat as a function of bar spacing.

Fourteen references.

Improved Measurement and Calculation of Heat Transfer from Condensed Steam in a Vertical Tube. (M. Jakob, S. Erk and H. Eck, Phys. Zeit., Vol. 36, No. 3, Feb., 1935, pp. 73-91.) (8.40/30557 Germany.)

A description is given of the apparatus with dimensioned sketches. Extensive experimental data are exhibited graphically.

A differential equation is formed from the rate of heat exchange in accordance with Nusselt's assumptions as to the thickness and velocity of the film of water

condensed on the surface of the tube. A solution is obtained by numerical methods and shows extensive similarities with observed phenomena.

Semi-empirical expressions are formed which give satisfactory numerical agreement with measurements.

Six references.

The Number of Water Drops Formed by Condensation on Various Solid Surfaces. (G. Tammann and W. Boehme, Ann. d. Phys., Vol. 22, No. 1, Feb., 1935, pp. 77-80.) (8.40/30558 Germany.)

Repeated condensation and evaporation shows that water drops reform on identical parts of a metal plate. Such favoured spots are evidently characterised by the presence of specially active atoms (noble metals) or oxides (base metals). The number of drops condensed on polished magnesium (1,000 per 0.01 mm.^{2}) is five times greater than on gold (200 per 0.01 mm.^{2}). Experiments with alcohol and benzol exhibit continuous films, not discrete drops.

The Thurston Rotor Cowl. (A. P. Thurston, J.R. Aer. Soc., Vol. 39, No. 293, May, 1935, pp. 445-447.) (8.426/30559 Great Britain.)

The cowl is formed of aerofoil vanes mounted on a rotating frame, coaxial with the (radial) engine. The system of rotating vanes may autorotate or may be driven in the opposite direction. In this latter case cooling air is drawn from the boundary layer and may postpone turbulence, with a corresponding reduction in head resistance.

Engines—Lubricants

Lowering of the Pour Point of Lubricating Oils by the Colloidal Method. (R. Kaladzhal, Chem. Absts., Vol. 28, No. 22, 20/11/34, p. 7507.) (8.540/30560 Russia.)

The effect of a mixture of triethanolamine and Al stearate and of " paraflow " on the pour point of automobile lubricating oils is compared, previously to dewaxing of the oil. Al stearate alone is not as effective as the mixture. Complete dewaxing is detrimental to the oil.

Storing and Loading of Palm Oil. (W. Loos, W.R.H., Vol. 16, No. 4, 15/2/35, pp. 59-62.) (8.540/30561 Germany.)

The article is chiefly concerned with storage tanks, pump and pipe lines (in Sumatra).

Experimental determinations are given of viscosity and specific gravity at temperatures from 27° to 31.5°.

Some Diesel Engine Lubrication Difficulties and Their Remedies. (A. Wolf, Chem. Absts., Vol. 28, No. 22, 20/11/34, p. 7495.) (8.540/30562 U.S.A.)

Addition of fatty acids increases the greater solvent property of the treated oil for asphaltic deposits and thereby improves the lubricating properties. Oils should be tested periodically for acidity.

Investigation of Chemical Stability of Automobile Oils. (L. Nikiforov and others, Chem. Absts., Vol. 28, No. 22, 20/11/34, p. 7496.) (8.54/30563 Russia.)

The oils were oxidised by the Butkov and Hardford method and also subjected to engine conditions. Asphaltene, carbene and carboid content were determined. The changes in the oil appear to be mainly due to cracking, which may take place on the metal surface at temperatures as low as 100°C.

The Use of Anti-Oxidants in the Stabilisation of Cracked Gasoline. (A. Degtyarèva, Chem. Absts., Vol. 28, No. 22, 20/11/34, p. 7504.) (8.54/30564 Russia.)

The best stabilisers are hydroquinine and pyrogallol. They are not affected by the material of the container.

New Developments in Lubrication. (G. W. Miller, Chem. Absts., Vol. 28, No. 22, 20/11/34, p. 7506.) (8.540/30565 U.S.A.)

If lubricating oil is subjected to chlorination in the presence of anhydrous Al Cl_3, a heavy semi-solid oil is obtained (paraflow). Small additions of this processed oil to normal oil will reduce the pour point and viscosity at low temperatures, without affecting the properties of the oil at high temperatures.

Oil Film Whirl. (B. L. Newkirk and L. P. Grobel, Trans. A.S.M.E., Vol. 56, No. 8, Aug., 1934, pp. 607-615.) (8.580/30566 U.S.A.)

It is stated that at or beyond twice critical shaft speed the oil lubricating film becomes unstable and the shaft whirls at its natural period. In the discussion the phenomenon is referred to as obscure and the hydrodynamical assumptions are challenged.

Six references.

Engines—Fuels

Application of Film Concept in Petroleum Refining. (C. C. Monrad, Ind. and Eng. Chem., Vol. 26, No. 10, Oct., 1934, pp. 1087-1092.) (8.60/30567 U.S.A.)

The evaporation from large plane surfaces is studied and equations are derived from the laws of heat transfer and diffusion.

Aircraft Engine Performance with 100 Octane Fuel. (F. D. Klein, J. Aer. Sci., Vol. 2, No. 2, March, 1935, pp. 43-47.) (8.640/30568 U.S.A.)

The Air Corps rating on the C.F.R. engine was employed (Specification 3566). The 100 octane fuel consisted either of standard reference fuel C_6 or of mixtures of iso-octane with petrol and isopentane, with from 1 to 8.5 cc. of ethyl lead per gallon. The tests were carried out on Wasp and Cyclone engines with compression ratio 6 and 6.4 respectively. General agreement with the C.F.R. rating of the fuel was obtained.

The higher octane number enabled the power output of the engine to be increased, with wider throttle opening, before detonation set in. The increase ranged from 70 h.p. to 160 h.p. and was relatively greater for the weaker mixtures. The higher power output was accompanied by a rise in mean cylinder head temperature (from 480° to 525°F.).

The better performance was confirmed by flight tests. The engines under test were not specially constructed for high knock rating fuels and still better results could be obtained by fitting the supercharger with inter-coolers. The provision of commercial iso-octane at a reasonable price should improve the performance of aircraft.

Influence of Temperature on the Explosion of Mixtures of Air and Hydrocarbons. (P. Mondain-Monval and R. Wellard, Comptes Rendus, Vol. 200, No. 3, 14/1/35, p. 232.) (8.64/30569 France.)

The hydrocarbon mixture under a pressure of 5 atmospheres is contained in a steel bomb and exploded by a spark. The rapidity of the explosion is registered by an indentation method. The experiment is repeated at increasing temperatures and at a critical temperature well below the auto-ignition tempera-

ture the explosion becomes extremely rapid. This fact is attributed to the presence of unstable chemical compounds formed during heating up.

Six references.

Fuels for Heavy Oil Engines. (L. J. le Mesurier and R. Stansfield, Chem. Absts., Vol. 28, No. 22, 20/11/34, p. 7495.) (8.640/30570 Great Britain.)

Cylinder liner wear is due to abrasive materials collected in the fuel oil during transit. The effect may be increased on sea-going installations by the presence of free H Cl from leakage of sea water into the crankcase.

Octane Number of Russian Petrols. (I. M. Kligerman, Chem. Absts., Vol. 28, No. 22, 20/11/34, p. 7505.) (8.640/30571 Russia.)

The following are representative values:—

Baku straight	75
,, cracked	81
,, naphtha	67
Grozny straight	68
,, cracked	73
"Trust NN"	57
Aviation NN	61

High Octane Fuel Tests. (W. R. Hopkins, Aero Digest, Vol. 26, No. 3, March, 1935, pp. 27-28.) (8.640/30572 U.S.A.)

Five fuels with octane numbers from 90 to 100 were tested by the fuel research staff at Wright field in a Wasp engine.

Specifications of the fuels show the general proportions of hydrocarbons and the amount of ethyl lead. Extensive test data as to horse-power, consumption, fuel flow, temperatures of cylinder heads, are drawn graphically.

Standardisation of Diesel Engine Fuel. (Fr. Sass, W.R.H., Vol. 16, No. 5, 1/3/35, pp. 67-71.) (8.640/30573 Germany.)

The quality of a Diesel fuel depends on the ease with which combustion is initiated and the completeness of the subsequent combustion. Ignition temperature and delay can be determined by laboratory methods (*e.g.*, cetene rating). Completeness of combustion (carbon residue) is more difficult to determine. The distillation curves and the coke number (Conradson test) give some indication.

The problem is of especial importance in the case of small high speed engines, where excessive wear accompanies the use of unsuitable fuel.

Fifteen references.

The Knocking of Motor Fuels and its Prevention. (E. Endo, Chem. Absts., Vol. 28, No. 22, 20/11/34, p. 7505.) (8.645/30574 U.S.A.)

The following alcohol mixtures are recommended:—

For engines with compression ratios up to 6.5—

Alcohol (98% purity)	15—20%
Ether	2—5%
Petrol	83—75%
or Alcohol (99% purity)	15—20%
Petrol	85—80%

For engines with compression ratios up to 7.5—

Alcohol (98% purity)	15—20%
Benzol	40%
Petrol	45—40%

Knocking Characteristics of Hydrocarbons. (W. G. Lovell and others, Ind. and Eng. Chem., Vol. 26, No. 10, Oct., 1934, pp. 1105-8.) (8.645/30575 U.S.A.)

Knocking characteristics of 103 pure hydrocarbons are given. The compression ratio of incipient detonation of a mixture of two compounds is not always the mean of the individual compression ratios weighted by the proportions in the mixture.

Eleven references.

The Resistance to Detonation of Different Isomeric Hydrocarbons. (Aubert and Duchêne, Chem. Absts., Vol. 28, No. 22, 20/11/34, p. 7505.) (8.645/30576 France.)

The tendency of fuel to detonate was measured by examination of photographs of spark explosions in a bomb, fitted with a compressor piston. The compression ratio was kept constant throughout, but the initial temperature was varied.

Benzene and toluene lose their effectiveness as anti-detonants with rise of initial temperature. Alcohol was unaffected.

Engines—Injection and Exhaust Systems

Automatic Engine Controls. (G. W. Knott, Flight, Vol. 27, No. 1374, 25/4/35, pp. 23-25, and No. 1379, 30/5/35, pp. 29-32.) (8.701/30577 Great Britain.)

The elementary principles are discussed and illustrated diagrammatically by characteristic curves of fuel consumption against throttle opening.

Improved Exhaust Tailpipe. (M. S. Kuhring, Canadian Aviation, Vol. 8, No. 2, Feb., 1935, pp. 10-11.) (8.721/30578 Canada.)

Sketches show the shape of various tail pieces, and arrows indicate the observed flow in the neighbourhood.

Tables show pressure readings at two stations and an advantage is claimed for the tail piece designed at the Ottawa engine laboratory of the National Research Council of Canada.

Oscillation in Exhaust Pipes of Internal Combustion Engine. (T. Schmidt, Z.V.D.I., Vol. 79, No. 1, 5/1/35, pp. 27-28.) (8.721/30579 Germany.)

Using data published by Waetzmann and Noether (Ann. d. Phys., Vol. 13, 1932, p. 212), an acoustic filter was constructed and fitted to a single cylinder two-stroke Diesel with crankcase scavenging. The filter consisted of four insulated chambers, through which the exhaust pipe passed, communicating with each chamber through adjustable holes. The silencer is placed close to the engine and silences the upper harmonics effectively, but allows free passage to the fundamental air vibration corresponding to the short exhaust pipe. With this arrangement the exhaust back pressure is low during the scavenging period and the working of the engine considerably improved.

The Functions of the Exhaust Valve. (R. J. Cousins, Airc. Eng., Vol. 7, No. 75, May, 1935, pp. 107-108.) (8.725/30580 Great Britain.)

Pressure is plotted against crank angle for different areas and timing of inlet and exhaust valves. The total available area for valve seatings is limited and the best compromise between relative size of inlet and exhaust valves is discussed in terms of the diagrams.

Engines—Pumps

Theory of Water-Jet Pump. (K. G. Klone, Z.V.D.I., Vol. 79, No. 3, 19/1/35, pp. 77-78.) (8.74/30581 Germany.)

The low efficiency of water jet pumps can be considerably increased by subdividing the jet and using cold water.

Junkers Free Piston Compressor. (K. Neumann, Z.V.D.I., Vol. 79, No. 6, 9/2/35, p. 155.) (8.745/30582 Germany.)

A combination of the opposed piston engine with an air compressor is constituted by designing the air piston (of increased diameter) as an extension of the power piston. There are no crankshafts, the piston assembly being kept in step by a system of coupling rods engaging with a centrally placed gear wheel. Combustion forces the piston outwards and compresses the air on the compressor side. Part of this air is delivered, but enough is retained to ensure the return stroke of the piston assembly and to provide the necessary scavenge air.

The article deals fully with the fundamental principle underlying this design (length of stroke, number of cycles per second, maximum pressure, etc.). Since no crankshaft bearings are employed high explosion pressure can be used, with corresponding thermal efficiency. Photographs show the compact appearance of the compressor which is built for pressures from 3 to 250 atmospheres at 500 to 1,000 strokes per minute. No details of the coupling system are given.

Influence of Bends in Fan Outlets. (L. S. Marks, J. H. Raub and H. R. Pratt, Trans. A.S.M.E., Vol. 56, No. 10, Oct., 1934, pp. 767-771.) (8.745/30583 U.S.A.)

Experimental data, exhibited graphically, appears to show that obstructions or bends in the intake have a serious effect in reducing delivery, while bends in the outlet have little effect. (The conditions cover a limited range.)

Two references.

Design and Performance of Axial Flow Fan. (L. S. Marks and J. R. Weske, Trans. A.S.M.E., Vol. 56, No. 11, Nov., 1934, pp. 807-813.) (8.745/30584 U.S.A.)

An aerofoil section with flat under-surface was selected and the details of a three-bladed fan design are shown graphically. Five and ten-blade guide vanes were installed and comparative tests made.

The mean velocity field round the hub is plotted. Relations between volume of air discharged, static pressure, power and efficiency, are shown graphically. The effect on efficiency of axial clearance between guide vanes and fan blade is shown separately.

Tests with and without diffuser are also shown. Noise measurements are recorded in decibels against volume delivered.

Engines—Transmission

A New Turbo-Transmission. (Autom. Ind., Vol. 72, No. 7, 16/2/35, p. 216.) (8.761/30585 U.S.A.)

A sketch of the general arrangement is given and a diagram shows torques and speeds of primary and secondary, and efficiency of transmission. It is known as the Voith turbo-transmission and is used in rail cars built by the Austro-Daimler-Puchwerke of Austria.

Armament

American Munitions. (G. H. Dern, Army Ordnance, Vol. 15, No. 89, March/April, 1935, pp. 263-267.) (9.0/30586 U.S.A.)

The rapid obsolescence and deterioration of military equipment and stores renders necessary a large manufacturing capacity. It is impossible to maintain, in peace time, Government establishments on a scale adequate for war. This can only be done by private industry.

Difficulties of controlling exports of raw materials and finished munitions are discussed.

Motion of High Pressure Gases and Compression Waves at the Muzzle of a Rifle. (K. Terazawa, M. Tamano and S. Hattori, Aer. Res. Inst., Tokyo, Report No. 117 (Vol. 9, No. 9), Jan., 1935.) (9.01/30587 Japan.)

Thirty-seven strips of cinema record are reproduced. An interpretation of the phenomena is given and numerical data obtained by measurement from the photographs are given graphically and in tables.

A description of the apparatus is given. (Original in Japanese, with English summary.)

Aeroplane Machine Gun Coupled to Engine. (Review of Patents.) (P. Léglise, Rev. de l'Armée de l'Air, No. 67, Feb., 1935, pp. 215-228.) (9.1/30588 France.)

The mechanism is described at length with fifteen diagrammatic sketches and the relative merits critically discussed.

On the Origin of the Luminosity Accompanying the Detonation of Explosives. (H. Muraour and A. Michel-Levy, Comptes Rendus, Vol. 200, No. 11, 11/3/35, pp. 924-926.) (9.03/30589 France.)

The luminosity is due to the rapid adiabatic compression of the surrounding gas by the shock wave. It is similar to that accompanying a powerful electric discharge.

Pattern Counter-Bombing of Aircraft Bombers. (A. Vanin, Riv. Aeron., Vol. 11, No. 2, Feb., 1935, pp. 233-246.) (9.3/30590 Italy.)

A bomb of 15 kg. has an effective radius of 80 m. according to the calculations given. Six fast fighters fly over a bomber and release 3×6 bombs in a pattern filling a parallelepiped, 800 m. long by 480 m. deep and 80 m. wide. The calculated probability of an effective hit is given as 54.5 per cent.

Chemical Warfare—(Europe Looks at). (A. H. Waitt, Army Ordnance, Vol. 15, No. 89, March/April, 1935.) (9.4/30591 U.S.A.)

Extracts from European literature on chemical warfare are given. Seven photographs are reproduced, illustrating gas barrages, smoke screens and gas shelters.

Materials—Characteristics, Defects and Treatment

Organisation of Research in the (German) Steel Industry. (K. Daeves, L.F.F., Vol. 11, No. 7, 14/1/35, pp. 185-188.) (10.100/30592 Germany.)

An account is given of the procedure in the firm with which the author is connected (Pereinigte Stahlwerke). The research is stated to be directed solely to the processes of steel making, but the boundary is not rigidly defined.

In the first place all relevant literature is examined and indexed by subject matter and the technical notices thus produced are circulated so as to render the information readily accessible to individual specialists employed by the firm.

These specialists are distributed through the shops, test and laboratory staff and touch is maintained with less directly relevant research through various institutions and societies.

Recent Developments in Special Steels. (A. Fry, W.R.H., Vol. 16, No. 4, 15/2/35, pp. 63-65. From Krupp Technical Reports, Sept., 1934.) (10.100/30593 Germany.)

A summary of progress is given under the headings of—Resistance to high temperatures, corrosion, acid reactions, fatigue and nitriding, low hysteresis and welding. Representative data are given in tables.

Ferrous Metallurgy in Aeronautics. (W. H. Hatfield, Airc. Eng., Vol. 7, No. 75, May, 1935, pp. 113-125, and No. 76, June, 1935, pp. 143-152.) (10.100/30594 Great Britain.)

Tables exhibit the composition, treatment and mechanical properties of 31 steels, specified in aircraft construction. Thermal, welding and magnetic properties are also tabulated. Micro-photographs × 200, show the grain of 22 steels.

A general survey deals with case-hardening, nitriding, machine welding and corrosion properties.

Six references.

Research on Engine Valve Steels. (I. Musatti and A. Reggiore, L'Aerotecnica, Vol. 15, No. 3, March, 1935, pp. 299-306. A review of research published in La Metallurgia Italiana.) (10.103/30595 Italy.)

Thirteen steels, partly of martensitic, partly of austenitic structure were examined for mechanical strength at temperatures ranging from 500°C. to 800°C. Chemical stability tests (oxidation and corrosion) were carried out over the same range. Best results were obtained with alloy steels with high Ni and Cr contents and small proportions of tungsten and silicon.

Fatigue of Shafts (at Press Fits, etc.). (R. E. Peterson and A. M. Wahl, J. of Applied Mechanics, Vol. 2, No. 1, March, 1935, pp. A-1 A-11.) (10.104/30596 U.S.A.)

Press fits produce stress concentrations and rubbing corrosion.

Extensive data are quoted from a German State railway report and further figures are given from the author's work in the Westinghouse research laboratories.

Stress optical diagrams are reproduced and from them are prepared diagrams of stress distribution over the surface of a press fit.

Seventeen references.

Fatigue Properties of Steel Wire. (S. M. Shelton and W. H. Swanger, Bur. Stan. J. Res., Vol. 14, No. 1, Jan., 1935, pp. 17-32.) (10.104/30597 U.S.A.)

Machining and polishing the surface as received from the manufacturers increased the fatigue strength by such figures as 40, 60 and 82 per cent. The results depended on the maximum stresses only and were independent of the mean stress.

Fourteen references.

The Welding of Heat Resisting Steel Alloys. (H. Schottky, Z.V.D.I., Vol. 79, No. 2, 12/1/35, pp. 41-47.) (10.140/30598 Germany.)

Welding steel alloys presents great difficulties if the weld is exposed to the action of unsymmetrical pressures and to corrosion. Such problems arise in

chemical technology. After careful study of the welding alloy, Cr. Mo. tubes carrying H_2 at 300 atmospheres pressure and 650°C. have been successfully welded by electric arc.

Twenty-three illustrations.

Weldability of High Tensile Strength Steels. (J. Muller, Z.V.D.I., Vol. 78, No. 44, 3/11/34, pp. 1293-1294.) (10.140/30599 Germany.)

Cracks and local hardening may appear near welds of thin steel strips (0.5 to 3 mm. thick). Hardening renders subsequent working difficult and affects the fatigue limits. Cracking may be reduced by a low $(P+S)$ content, especially if the per cent. C. exceeds 0.2 per cent.

Hardness is controlled by selection of a suitable C. or Mo. alloy steel and by subsequent heat treatment. Methods of inspection for cracking and hardening are described.

Three references.

Specifications for Welded Ship Hulls. (R. Schmidt, W.R.H., Vol. 16, No. 2, 19/1/35, pp. 21-24.) (10.140/36600 Germany.)

In the light of more extensive experience, modified specifications for welding hull plates have been issued by the German Standards Committee.

A critical comment is given with sketch illustrations.

Four references.

Welding of Iron and Steel—Symposium of Iron and Steel Institute. (Engineer, Vol. 159, Nos. 4140-4144, May-June, 1935, pp. 506-509, etc.) (10.140/30601 Great Britain.)

The number of papers presented was about 150. Summaries of 32 papers and of the subsequent discussion are given.

Formation of Blisters in Heat Treatment of Aluminium Alloys. (W. Gatzek, L.F.F., Vol. 11, No. 3, 18/8/34, pp. 65-73. D.V.L. Report 33/06.) (10.231/30602 Germany.)

Specifications of twelve alloys are given. Systematic tests were carried out in a vacuum and in various gases, with heat treatment in a salt bath and in the electric oven.

It appears that the formation of blisters is not an inherent property of the alloy, although the tendency to blister formation increases with the magnesium content. The source of trouble is the release of free hydrogen which can be removed by previous heating in a vacuum. For this reason the presence of water vapour is to be avoided during melting. If preliminary removal of hydrogen is not possible the electric oven is preferable to the salt bath.

Photographs show 47 test pieces, microstructure and blistering effects.

Nine references.

Applications of Beryllium Alloys in Watch Making. (W. Rohn, Z.V.D.I., Vol. 79, No. 1, 5/1/35, pp. 22-23.) (10.234/30603 Germany.)

A beryllium content of 1 per cent. in steel and non-ferrous alloys is stated to produce remarkable qualities of invariance and robustness. Such alloys are non-magnetic and have applications in the manufacture of watch springs.

Two references.

The Influence of Beryllium on Steel. (W. Kroll, Z.V.D.I., Vol. 79, No. 1, 5/1/35, pp. 28-29.) (10.234/30604 Germany.)

English experimenters have failed to confirm the results of German scientists as to the beneficial effect of Be on certain steels. The authors attribute the

failure to unsuitable melting furnaces and to the use of Ni-C steels. Without certain precautions Be attacks the fire-resisting lining of cupolas instead of dissolving in the steel.

The beneficial effect is, moreover, restricted to certain classes of Ni-Cr steels. Under the combined action of temperature control, nitriding and ageing, a tool steel is produced which combines a glass hard surface with a tough core.

Elastic Properties of Timbers. (J. Stamer, Ing. Arch., Vol. 6, No. 1, Feb., 1935, pp. 1-8.) (10.400/30605 Germany.)

Photographs show test pieces cut normally, tangentially and radially, with reference to the axis determined by the annual rings, as closely as the asymmetry of growth allowed. The moisture content was kept approximately the same in most specimens.

Eight kinds of timber were tested and the measured values of density, moisture and elastic moduli are given in Table I. The influence of the cross sectional shapes on the apparent shear moduli is shown in Table II, and the influence of the direction of cutting in Table III.

Great uncertainties arise in assuming average values of the moduli and applying the elastic theory of isotropic bodies; test measurements on a model beam gave 1,200 kg./cm.^{2} as the ultimate strength, while a full-scale test on a large beam gave only 250 kg./cm.^{2}. The problems thus raised are discussed in the following paper (see Abstract 30606).

Eight references.

Elastic Theory of Anisotropic Bodies Applied to Timber Measurements. (H. Horig, Ing. Arch., Vol. 6, No. 1, Feb., 1935, pp. 8-14.) (10.400/30606 Germany.)

Following Voigt's notation for the rhomboidal system of crystal structure nine moduli and nine coefficients are introduced into the usual stress-strain relations. These quantities are determined from the experimental measurements and tabulated for the same timber as in the previous article.

Voigt's values of the moduli of rhombic crystals of baryte, aragonite and topaz are tabulated for comparison. The results are also expressed in terms of the usual engineering moduli. It is easy to recognise general similarities imposed by the similar fibrous structure of the various timbers.

Three references.

Variation in Density of Important Conifer Timbers According to Region where Grown, Location of Tree and Individual Trees. (R. Trendelenberg, Z.V.D.I., Vol. 79, No. 4, 26/1/35, pp. 85-89.) (10.400/30607 Germany.)

The moisture content of timber depends remarkably on the place of growth. It is possible to produce timber of predetermined moisture by selection of location.

Moisture Relations of Aircraft Fabrics. (G. M. Kline, Bur. Stan. J. Res., Vol. 14, No. 1, Jan., 1935, pp. 67-84.) (10.402/30608 U.S.A.)

Balloon cloth, airship outer cover and aeroplane fabrics treated and untreated were exposed in a bell jar to various degrees of humidity above and below the equilibrium value and the rate of change of weight with time was observed.

Numerical values are given in extensive tables.

Eleven references.

Influence of Previous Heat Treatment on Physical Qualities and Structure of Glass. (S. Erk, F.G.I., Vol. 6, No. 1, Jan./Feb., 1935, pp. 33-39.) (10.406/30609 Germany.)

Glasses may be considered as polymerised fluids. With decreasing temperature the polymerisation increases and the rate of polymerisation decreases

rapidly. Some of the author's results can be extended to artificial resins, which find increasing application as electrical insulators.

Twenty references.

Photo-Elastic Properties of Soft Vulcanised Rubber. (W. E. Thibodeau and A. T. McPherson, Bur. Stan. J. Res., Vol. 13, No. 6, Dec., 1934, pp. 887-896.) (10.408/30610 U.S.A.)

The composition is given of thirteen rubber preparations with from 0.3 to 8 per cent. weight of sulphur. A description is given of the apparatus.

The results are shown graphically and a correlation is given between sulphur content and the three coefficients of an empirical cubic relation for optical retardation.

Longitudinal Shear in "Checked" Wooden Beams. (J. A. Newlin, G. E. Heck and H. W. March, Trans. A.S.M.E., Vol. 56, No. 10, Oct., 1934, pp. 739-744.) (10.420/30611 U.S.A.)

(A check is a fissure along the grain of the beam.)

The elementary mathematical theory for isotropic material is applied with modifications of the boundary conditions brought in by the presence of fissures.

A beam was built up with an artificial fissure in the neutral plane. In the neighbourhood of the fissure the resistance of the beam approaches that of two superposed beams sliding freely over each other.

Results of tests are tabulated and plotted for comparison with the extreme "two-beam" values, which give lower limits.

Testing Apparatus and Methods of Testing

Plane and Image Methods of Representing Ground Effect in Tests on Vehicle Models. (R. H. Heald, Bur. Stan. J. Res., Vol. 13, No. 6, Dec., 1934, pp. 863-870.) (11.10/30612 U.S.A.)

Wind channel tests on models of motor cars and trains were made with fixed planes representing the ground and with two models in mirror image positions. When the leading edges were faired the figures obtained by the two methods for streamlined automobiles agreed within about 1 per cent. Results for a train model differed by about $3\frac{1}{2}$ to $4\frac{1}{2}$ per cent.

The presence of the fixed plane with boundary layer is obviously not strictly equivalent to the plane of symmetry of the mean flow in the image method.

Air Forces and Yawing Moments on Three Automobile Models. (R. H. Heald, Bur. Stan. J. Res., Vol. 13, No. 6, Dec., 1934, pp. 871-878.) (11.14/30613 U.S.A.)

Three models are shown in profile sketches with the method of mounting on the air channel balance. Yawing moments and lift drag and cross-wind forces are given graphically as functions of yaw angle. Full-scale values are computed and tabulated.

Problems of Naval Aviation. (Lt. Lenoir, Rev. de l'Armée de l'Air, No. 66, Jan., 1935, pp. 3-20.) (11.22/30614 France.)

Experiments with an aeroplane equipped with emergency floats are described and illustrated by photographs. The problems of deck landing are discussed mathematically at length.

Aerostats—Materials

Permeability of Synthetic Film Forming Materials to Hydrogen. (T. P. Sager, Bur. Stan. J. Res., Vol. 13, No. 6, Dec., 1934, pp. 879-885.) (12.42/30615 U.S.A.)

Specifications are given of the chemical constitution and relevant physical properties of film forming materials, with suitable solvents. A brief consideration of weight, permeability, hygroscopic property and chemical stability, shows anomalies which prevent any simple correlation.

Hitherto, highly hygroscopic materials have been largely used on account of their low permeability, in spite of the disadvantage of variations in weight. It is considered that less hygroscopic material may become available in the near future.

Twelve references.

Wireless

Proportion of Radiated Energy from a Vertical Dipole Absorbed by the Earth. (K. F. Niessen, Ann. d. Phys., Vol. 22, No. 2, Feb., 1935, pp. 162-188.) (13.30/30616 Germany.)

The electro-magnetic equations are written down in polar co-ordinates and solutions are developed in integrals of products of Bessel functions and exponentials.

Numerical values are computed for assumed conductivities of salt and fresh water and for moist and dry soil. The results are exhibited graphically and in numerical tables.

Four references.

Automatic Syntraction of Two Broadcast Carriers. (V. V. Gunsolley, Proc. Inst. Rad. Eng., Vol. 23, No. 3, March, 1935, pp. 244-248.) (13.30/30617 U.S.A.)

Author's Abstract.—A phase meter is adapted to control automatically the space-phase between two carriers at any described point in the area of common frequency broadcasting.

Experimental results of syntraction between a crystal controlled oscillator and broadcast carrier are given.

An Objective Method for Measuring the Wave Length of High Frequency Sound Waves. (J. Zühlke, Ann. d. Phys., Vol. 21, No. 7, Jan., 1935, pp. 667-670.) (13.30/30618 Germany.)

Wave-lengths of the order of 200 μ are measured with an error of ± 10 μ by a photographic recorder applied to Pierce's standing wave apparatus.

Three references.

Radio Interference. (E. A. Smith, J. Frank. Inst., Vol. 218, No. 6, Dec., 1934, pp. 653-663.) (13.32/30619 U.S.A.)

A summary is given of sources of interference, with particular reference to high voltage electric power supply transmission systems. Examples of interference are given graphically and devices for prevention and shielding of high frequency discharges are discussed briefly.

Apparatus for Recording Average Amplitude of Wireless Echoes. (F. J. Farmer, Proc. Camb. Phil. Soc., Vol. 31, Pt. 2, April, 1935, pp. 295-302.) (13.32/30620 Great Britain.)

Diagrams of connections show the circuits employed, with pulse transmitter, cathode ray oscillograph, synchronised time base, amplifiers and diodetectors.

Calibration curves and records of signals and echoes on a wave-length of 150 m. are reproduced.

Designing Resistive Attenuating Networks. (P. K. McElroy, Proc. Inst. Rad. Eng., Vol. 23, No. 3, March, 1935, pp. 213-233.) (13.40/30621 U.S.A.)

The usual expressions developed in the theory are collected and computation is facilitated by numerical tables of factors which occur frequently.

Three references.

Horizontal Rhombic Antennas. (E. Bruce, A. C. Beck and L. R. Lowry, Bell Tele. Pubcn. No. 835.) (13.4/30622 U.S.A.)

Photographs show details of a rhombic receiving aerial and its mounting on a pole-mast with guy control from the ground. Each side of the rhombus was $3\frac{1}{4}$ wave-lengths. A gain of 14 decibels was shown over a half wave horizontal dipole at the same height. A simplified theory is developed and vibration intensity fields calculated. Best dimensions, rhombic angle, height and orientation are determined by the theory.

In practice satisfactory compromises with working conditions can be made. Experimental measurements lie well on the calculated curves of field intensity.

Theory of Electron Gun. (I. G. Maloff and D. W. Epstein, Proc. Inst. Rad. Eng., Vol. 22, No. 12, Dec., 1934, pp. 1386-1411.) (13.5/30623 U.S.A.)

The principle of the electron gun is to generate, control and concentrate an electron team on to a required spot. The theory of electron lenses with detailed analysis of the action of the various parts of the gun is given.

Five references.

An Electron Oscillator. (B. J. Thompson and P. D. Zottu, Proc. Inst. Rad. Eng., Vol. 22, No. 12, Dec., 1934, pp. 1374-1385.) (13.60/30624 U.S.A.)

Authors' Abstract.—A new type of thermionic tube, capable of producing ultra-high frequencies by means of electron oscillations, has parallel plane electrodes, instead of cylindrical electrodes as in the conventional Barkhausen-Kurz tubes, and a fourth element called a backing plate.

The relations between wave-length and amplitude of oscillation and electrode potential are shown by measurements on a typical tube. The filament voltage is not critical, space-charge-limited operation is satisfactory, and only one mode of oscillation is obtained. Both factors appear to give these tubes an advantage in stability over cylindrical Barkhausen-Kurz tubes.

A tube of the flat type described has produced oscillations at a wave-length of less than 10 centimetres in the fundamental mode with a positive grid potential of 150 volts.

Five references.

Vacuum Tubes for Ultra-High Frequencies. (C. E. Fay and A. L. Samuel, Proc. Inst. Rad. Eng., Vol. 23, No. 3, March, 1935, pp. 199-212.) (13.6/30625 U.S.A.)

Authors' Abstract.—The failure of the conventional vacuum tube to oscillate above some critical frequency is analysed and illustrated by a tube which will oscillate at frequencies up to 300 megacycles.

A Barkhausen tube giving output of the order of five watts in the range from 450 to 600 megacycles is described. For higher frequencies (up to 2,500 megacycles) spiral-grid Barkhausen tubes have been used.

By departing from conventional construction principles, it is possible to extend the operation of negative grid oscillators above 300 megacycles, one tube described giving six watts at 500 megacycles with an efficiency of 19 per cent.

By further refinement appreciable power has been obtained at 1,000 megacycles and the possibilities have by no means been exhausted.

Fifteen references.

Ultra-Short Waves in Radio Communication. (F. A. Kolster, Proc. Inst. Rad. Eng., Vol. 22, No. 12, Dec., 1934, pp. 1335-1353.) (13.6/30626 U.S.A.)

Author's Abstract.—In general, this paper deals with the generation and practical utilisation of ultra-short waves below ten metres. The first part of the paper describes an ultra-high-frequency oscillator in which a " tank circuit " of novel design is used for the purpose of obtaining a high degree of frequency stabilisation without resorting to frequency doubling or crystal control. Later, the feasibility of utilising ultra-short waves as carriers of signal channels from a remote receiving station to the city operating room is discussed and preliminary experiments described.

Behaviour of Biological Objects under High Frequency Radio. (H. Danzer, Ann. d. Phys., Vol. 21, No. 8, January, 1935, pp. 783-790.) (13.6/30627 Germany.)

Physiological aspects of the phenomena are discussed, in particular the conductivity of the blood under short wave radiation. Details of the apparatus employed for measurements under very short and medium wave-length radiation are given.

The electrical resistance, shown graphically, drops to about one-third for ultra-short wave-lengths. A comparison with the theory gives only qualitative agreement.

Eight references.

Ultra-Short Radio Waves as Higher Harmonics in Space Charge Oscillations. Part I. (J. Muller, Ann. d. Phys., Vol. 21, No. 6, Jan., 1935, pp. 611-648.) (13.6/30628 Germany.)

A modified Barkhausen circuit is described for the production of ultra-short waves of length determined by the natural period of the grid spiral. Design details of experimental valves are given.

Computed and calculated values are tabulated and show satisfactory agreement.

Radiating Properties of Antennas. (C. A. Nickle, R. B. Dome and W. W. Brown, Proc. Inst. Rad. Eng., Vol. 22, No. 12, Dec., 1934, pp. 1362-1373.) (13.70/30629 U.S.A.)

Authors' Abstract.—A system of tuning is described by which the current distribution and therefore the radiating properties of an antenna may be varied over wide range. This is effected by a localised capacity and inductance connected to the top of the radiator. The capacity may conveniently take the form of a sphere, a cylinder, or a disc. The inductance may take the form of a coil housed within the sphere or cylinder or of two parallel wires. By appropriate adjustment the current distribution may be varied.

Frequency Effects in Photo-Electric Cells. (W. Leo and C. Müller, Phys. Zeit., Vol. 36, No. 4, 15/2/35, pp. 113-122.) (13.7/30630 Germany.)

A description is given of the apparatus installed at the Physikalisch-Technische Reichsanstalt, for exposing photo-electric cells to a beam of accurate sinusoidal light intensity and constant frequency.

The results are given graphically in twelve diagrams, and marked differences are shown.

In some cases cæsium cells show a sensible falling off in the response at from 300-1,000 cycles, while a cuprous oxide boundary layer cell maintains full response up to 5,000 cycles.

The effects of the area of illuminated surface, the light intensity and the spectral distribution of beam intensity remain to be further investigated.

Ten references.

Photo-Electric Apparatus for Measuring High Air Speeds. (Luftwissen, Vol. 1, No. 11, 15/11/34, p. 318.) (13.70/30631 Germany.)

A brief description is given of a camera with two lenses. One lens is directed at the aeroplane and shows calibrating marks in the field; the other lens at two chronometers, one controlled by a tuning fork in a thermostat and the other electrically synchronised with the corresponding chronometers at the other end of the measured distance. A chronometer rate of 0.06 seconds in twenty-four hours is obtainable.

One reference.

Photography

Cinema-Metallography. (E. O. Bernhardt and H. J. Wiester, Z.V.D.I., Vol. 79, No. 1, 5/1/35, pp. 7-11.) (14.28/30632 Germany.)

A description is given of polarising microscope and cinematograph apparatus for taking metallograph film records at the rate of 20 per second, under progressive cooling of the metal.

Records are reproduced and show the sudden appearance of needles of martensite on the surface of austenite within the interval of 1/20th second. Other records show the small beginnings of a tin crystal formation and its almost complete formation in the following record, the time of formation being slightly greater than 1/20th second. Reference is made to other applications.

Eleven references.

Modern Processes for Making Blue Prints. (A. Schade, Z.V.D.I., Vol. 79, No. 5, 2/2/35, p. 139-142.) (14.60/30633 Germany.)

Ordinary blue prints require washing in water and subsequent drying. Modern papers can be developed in a semi-dry or completely dry state, with improved speed of operation and clearness of detail.

Acoustics, Noise Reduction, etc.

Acoustic Fixing of Aircraft. (P. Léglise, Rev. de l'Armée de l'Air, No. 66, Jan., 1935, pp. 37-59, and No. 67, Feb., 1935, pp. 147-172.) (15.25/30634 France.)

The author states that the problem has been thoroughly explored only in France, U.S.A., Czechoslovakia and Germany, but has not been the subject of serious work elsewhere.

Directional listeners are more accurate than the unaided ear, but without mechanical corrections for course and speed the time error and corresponding range error impose costly and ineffective barrage fire.

Reference is made to infra-red and heat-ray detection, but in spite of the remarkable results obtained in star observations, the application of aircraft detection is disappointing by reason of local temperature variation near the receiver. The latter method has been tried and abandoned in France five years ago. The directional reception of electro-magnetic radiation from the magneto is completely prevented by suitable shielding.

Only the acoustical method is considered at length. A description is given of combined visual and aural direction fixing, whereby the mechanical corrections

can be directly checked. A searchlight is coupled to the telescope and it is stated that once an aircraft has been picked up by it, escape from the beam is very difficult. Results of trials are tabulated and give a high proportion of successful fixes.

A schematic view is given of the Goerz system of acoustic fixing with four four-gun A.A.C. batteries mechanically controlled by the acoustic position fixers.

An exposition is given of the elementary geometry and kinematics of the problem of fixing from two acoustic stations on a base line, with a detailed account of mechanical devices for recording the altitudes and azimuths, and mechanical methods of determining the speed and allowing for the change of position during the acoustical time lag.

Acoustic Threshold Values (IV). (E. Waetzman and L. Keibs, Ann. d. Phys., Vol. 22, No. 3, March, 1935, pp. 247-256.) (15.20/30635 Germany.)

Various methods of measuring the damping of sound waves in pipes are discussed.

The ratio of pressures at successive wave peaks is measured, for frequencies from 400 to 1,400.

Observed values of the damping coefficient are greater by about 8 per cent. than values calculated from Kirchoff's formula. The damping increases with frequency.

Six references.

Effect of Skewing Slots on Noise in Electrical Machinery. (S. J. Mikina, Trans. A.S.M.E., Vol. 56, No. 10, Oct., 1934, pp. 711-720.) (15.30/30636 U.S.A.)

Skewing the slots by one slot pitch reduces the periodic variation in magnetic inductance to a relatively negligible amount, with corresponding reduction in hum from this source. The elementary mathematical theory is worked out.

Two references.

Trans-Ocean Air Transport—Conference W.G.L., Jan., 1935. (Luftwissen, Vol. 2, No. 1, Jan., 1935, pp. 11-13.) (15.5/30637 Germany.)

A summary is given of ten papers read at the XXIII Meeting of the Scientific Society for Air Navigation, 21st/22nd January, 1935:—

(1) Foreign States in reference to oversea and coastal air transport in the North and South Atlantic. (H. N. Wronsky, Jun.)

(2) German trans-oceanic air transport. (Buddenbrock.)

(3) Development of long range oversea flights by non-German countries in recent years. (R. Schulz.)

(4) Problems of long range flights. (Dipl. Ing. Koster.)

(5) Meteorological problems of trans-Atlantic air transport. (Prof. Dr. Seilkopf.)

(6) Long range air navigation over land and sea in Germany and other countries. (Kpt. Niemann.)

(7) Wireless navigation in the South Atlantic. (Dr. Dierbach.)

(8) Development and present state of automatic control in other countries. (Dr. Wunsch.)

(9) Equipment of aeroplane tenders and carriers in other countries. (W. Bartz.)

(10) Scientific problems and observations, particularly in free balloons. (P. Perlewitz.)

Accidents and Precautions

Investigation of Accident to Flying Boat "Sirohato." (Aer. Res. Inst., Tokyo, Report No. 116 (Vol. 9, No. 8), Jan., 1935.) (16.00/30638 Japan.)

The report (in Japanese) is illustrated by over two hundred photographs, sketches and diagrams. An extensive summary is given in English. The meteorological conditions are discussed with weather maps and tables of data.

The accident is attributed to the disconnecting of a turnbuckle on an aileron cable. The cable was too short and an insufficient number of screw threads were engaged. No mention is made of locking the turnbuckle. It is supposed that the turnbuckle became unscrewed in bumpy weather, leaving the aileron free to oscillate, and that subsequent fluttering of the wings produced rupture.

The conditions of the accident were reconstructed in the laboratory and wind channel.

Building Precautions Against Air Attack. (G. Rüth, Z.V.D.I., Vol. 79, No. 1, 5/1/35, pp. 13-21.) (16.00/30639 Germany.)

Seven photographs show examples of damage done by bombs.

Forty-one architectural drawings illustrate suggestions for reinforcement of building structures against bomb attack. In large buildings the space occupied by the staircase and well is more suitable for provision of bombproof shelters than the cellar.

The mitigation of fire risks is discussed and costs of converting buildings are estimated.

Three references.

Aircraft—Unorthodox

Wingless Autogiro. (Sci. Am., Vol. 152, No. 3, March, 1935, pp. 148-149.) (17.05/30640 U.S.A.)

Photographs show the general appearance and some details, particularly the inverted control columns. A specification of performance is given.

Mathematical Theory of Flapping Flight. (W. Schmeidler, Z.A.M.M., Vol. 14, No. 3, June, 1934, pp. 163-172.) (17.10/30641 Germany.)

Potential flow of an ideal inviscid fluid is assumed and expressions are written down for the components of air forces acting on the wing and for the circulation. The double integrations over a cycle of flapping motion and over the wing's surface are difficult. A numerical example is worked out and gives 7 h.p. for 274 kg.

Three references.

Flapping Flight by Man-Power. (A. Piskorsch, Flugsport, Vol. 27, No. 1, 9/1/35, pp. 7-12, and No. 2, 23/1/35, pp. 26-31.) (17.10/30642 Germany.)

Mechanical details are discussed and illustrated by sketches. The reciprocating forces are supplied by the strain energy of the spring mounting. The aerodynamics of pulsating wing motion is discussed in elementary terms.

Aircraft Carriers

The Aeroplane on Board the Submarine. (I. A. Gavrilof, U.S. Nav. Inst. Proc., Vol. 61, No. 383, Jan., 1935, pp. 17-23.) (18.2/30643 U.S.A.)

The long immunity of the German merchant steamer "Wolf" as a raider is attributed to the skilful use of the seaplane carried on board. Submarines fitted to carry seaplanes have great tactical and strategic possibilities.

The loss of the M.2 seaplane-carrying submarine is attributed to failure of the air shed under water pressure and indicates the chief difficulty of design.

Meteorology and Physiology

Wind Pressure on Buildings. (O. Flachsbart, Trans. A.S.M.E., Vol. 56, No. 8, Aug., 1934, p. 584.) (19.10/30644 U.S.A.)

In an abstract of the original paper elementary formulæ are quoted and numerical examples are given from measurements on buildings.

Nature of Lightning Discharges. (H. Norinder, J. Frank. Inst., Vol. 218, No. 6, Dec., 1934, pp. 717-738.) (19.10/30645 U.S.A.)

A description is given of a cathode ray oscillograph for recording the disturbances set up by lightning discharges without fogging the photographic plate. Two hundred and ninety discharge records were made within 16 km. of the station. The results are partially analysed and data as to intensity and time of discharge are deduced.

Four photographic records are reproduced and intensity of field is plotted against time in diagrams. A diagram of intensity as a function of distance shows wide scattering within fairly well defined upper limits, negative and positive records being roughly equal in number.

Five references.

Ionising Effect of Meteors. (A. M. Skellett, Bell Tele. Pubcn., No. 853, and Proc. Inst. Rad. Eng., Vol. 23, No. 2, Feb., 1935, pp. 132-149.) (19.10/30646 U.S.A.)

The observational evidence for ionisation by impact of a meteor is discussed. Successful correlations have been made of bright meteor observations with increase in atmospheric ionisation.

Thirty-five references.

Weather's Third Dimension (Upper Air Research). (P. Del Vecchio and D. Sayre, Aviation, Vol. 34, No. 3, March, 1935, pp. 86-88.) (19.10/30647 U.S.A.)

Daily air soundings up to 5 or 6 kilometres are carried out at 20 stations in U.S.A.

Carburettor Ice Formation. (Sci. Am., Vol. 152, No. 3, March, 1935, p. 151.) (19.15/30648 U.S.A.)

Brief details are given of a research installation on a Lockheed " Orion " for investigation of ice formation and prevention.

Equipment

Air Mail Pick-up. (Sci. Am., Vol. 152, No. 3, March, 1935, p. 151.) (20.10/30649 U.S.A.)

A metal chute turning with the wind has a wide vee entrance narrowing down to a slot. The passing aeroplane trails a cable carrying a mail sack, which enters the chute and is released. Immediately after a catapult launches a mail sack for collection in the direction of flight and a mechanical device attached it to the trailing cable. A shock absorber is fitted to the aeroplane end of the trailing cable.

Lighting

Maxwell Colour Triangle with Uniform Chromaticity Scales. (D. B. Judd, Bur. Stan. J. Res., Vol. 14, No. 1, Jan., 1935, pp. 41-57.) (21.22/30650 U.S.A.)

Trilinear co-ordinates in terms of red, blue and green standards determined by trial and error give differences of stimuli very nearly proportional to the length of any straight line segment in the triangle.

Forty references.

Improvements in Lighting at Tacoma. (R. L. Kelly, Aero Digest, Vol. 26, No. 3, March, 1935, pp. 14-15.) (21.15/30651 U.S.A.)

A technical descriptive account is given of the lighting equipment of the air port. The octagonal lighting scheme and landing ways are shown in a photograph and a diagram.

Aerodynamics and Hydrodynamics

Neutral Equilibrium of Eddy Filaments. (A. Kneschke, Z.A.M.M., Vol. 14, No. 3, June, 1934, pp. 178-183.) (22/30652 Germany.)

The problem is restricted to two-dimensional velocities with transverse lines of vorticity. Reference is made to the relation between Routh's stream function and Kirchoff's hodograph function.

An example is worked out for a symmetrical eddy pair and three types of hodographs are shown graphically, each having one position of equilibrium.

Coefficient of Viscosity of Water and Other Substances in Terms of Physical and Chemical Constants. (W. Schmidt, W.R.H., Vol. 16, No. 2, 19/1/35, pp. 19-21.) (22/30653 Germany.)

Empirical numerical relations are given between viscosity of water and hydrocarbons, and melting temperature, critical vapour temperature and number of atoms in the molecule. Applications to lubricants and melted alloys are suggested.

Measurements of Viscosity in Molten Silica. (W. M. Cohn, Ann. d. Phys., Vol. 21, No. 8, Jan., 1935, pp. 761-782.) (22/30654 Germany.)

The viscosity was determined by observation of spheres of platinum rhodium alloy falling freely in molten silica. The passage of the falling sphere through fixed coils was determined by radio transmission apparatus. The results are shown in four tables and in six diagrams.

Thirty references.

Hydrodynamical Resistance of Rods. (G. Sprick and A. Becker, Ann. d. Phys., Vol. 22, No. 2, Feb., 1935, pp. 195-208.) (22/30655 Germany.)

Rate of fall of circular cylindrical rods with hemispherical ends was observed in water and in glycol. The results are shown in numerical tables and graphically. The resistance is given as a function of velocity and the coefficient of resistance as a function of Reynolds number from 2 to 130.

Three references.

Flow Round Plates and Wing Profiles of Small Aspect Ratio. (H. Winter, F.G.I., Vol. 6, No. 1, Jan./Feb., 1935, pp. 40-50, and No. 2, March/April, 1935, pp. 67-71.) (22/30656 Germany.)

The aspect ratio, span/chord, varies from 2 to $\frac{1}{2}$ in the 37 models listed. The plan forms are rectangular, elliptic, half-elliptic and triangular. Families of polar curves and lift, drag and moment curves as functions of incidence are given in 18 diagrams. Pressure distributions are also given graphically.

Photographs of smoke jets and of etching on end plates give some visual idea of the general flow round the models.

Seventeen references.

Viscosity of Emulsion in Water. (R. Hermann, F.G.I., Vol. 6, No. 1, Jan./Feb., 1935, pp. 1-8.) (22/30657 Germany.)

The emulsion contained fine particles of clay in suspension, the time allowed for settling of the heavier particles ranging from 2 to 190 days. Fluidity is

defined as the inverse of the apparent viscosity and experimental values are plotted against the tangential pressure on the wall of the tube. The observed results are plotted graphically and show that the fluidity increases (the viscosity decreases) with increasing tangential pressure on the wall (increasing pressure gradient and increasing velocity).

The tangential pressures range from 0-30 bars (dynes/cm.^{2}) so that the pressures (and velocities) are small. By extrapolation to zero the fluidity is made to disappear for zero velocity (a result which throws doubt on the validity of the extrapolation).

It appears to be established that the emulsions do not exhibit constant apparent viscosity for low Reynolds numbers.

Twenty-five references.

Subsoil Flow. (G. Hamel, Z.A.M.M., Vol. 14, No. 3, June, 1934, pp. 129-157.) (22/30658 Germany.)

The problem is reduced by drastic simplification to ideal two-dimensional potential flow, expressed in terms of complex quantities. Elegant examples are worked out.

In the last paragraph reference is made to the physical impossibility of infinite velocities at the boundary and a corrective term for the transition layer is constructed.

Five references.

Recent Research on Fluid Mechanics. (T. v. Kármán, W. Bollay and A. J. Ippen, J. of Applied Mechanics, Vol. 2, No. 1, March, 1935, pp. A.28-A.32.) (22.10/30659 U.S.A.)

A brief summary is given of recent work under headings such as potential flow, laminar viscous fluid, turbulence and skin friction, vortex motion, cavitation, etc.

A comprehensive bibliography of 174 references is added.

Circulation in Vacuum Pans. (A. L. Webre, Trans. A.S.M.E., Vol. 56, No. 12, Dec., 1934, pp. 913-922.) (22.10/30660 U.S.A.)

The convection flow in sugar boilers is investigated and temperature variations are recorded.

Thirty Years of Research in Fluid Mechanics. (D. P. Riabouchinsky, J.R. Aer. Soc., Vol. 39, No. 293, May, 1935, pp. 377-444.) (22.10/30661 Great Britain.)

The author was in charge of work at the Koutchino Laboratory, near Moscow, instituted in 1904. His paper covers a wide range of original experimental and mathematical contributions and is an important historical document. The author's influence on aerodynamical research has probably been much greater than he seems to think.

A list of 105 papers by the author is given.

Resistance to Rotation of a Disc Immersed in a Viscous Fluid. (S. Goldstein, Proc. Camb. Phil. Soc., Vol. 31, Pt. 2, April, 1935, pp. 232-243.) (22.15/30662 Great Britain.)

v. Kármán's rough approximate solution for laminar motion has been put on an accurate basis by Cochran, Proc. Camb. Phil. Soc., 365-375, 1934. The solution for turbulent motion necessarily depends on empirical expressions such as the well known v. Kármán parabola of the seventh power for the velocity gradient. This has since been replaced by an empirical logarithmic relation of

considerable generality, also due to v. Kármán, which lends itself to the extensive transformations and integrations of the present paper.

The two formulæ are plotted against experimental values and a reasonable fit is exhibited with moderate scattering.

Instability of a Thread of Viscous Fluid Surrounded by Another Viscous Fluid. (S. Tomotika, Proc. Roy Soc., Vol. 150, No. 870, 1/6/35, pp. 322-337.) (22.15/30663 Great Britain.)

The equations of viscous fluid motion are formed in cylindrical co-ordinates (r, θ, z) referred to the axis of the thread as axis of symmetry, and simplified by neglecting terms containing squares and products of velocity components and derivatives. The assumption is made that the motions contain the factor exp. $(qt + ikz)$ and two solutions are found in terms of Bessel functions of r only.

Boundary conditions are introduced and elimination of four arbitrary coefficients leads to a fourth order determinant, which is reduced to a form determining the ratio of the wave-length to the radius. A limiting case reduces to a particular form worked out by Rayleigh.

In another example the numerical values of the data are taken from experimental work by G. I. Taylor and the solution is computed for comparison with Taylor's experimental results. The size of the drops observed by Taylor agrees with the size determined by the calculated wave-length of instability, within about 13 per cent.

Five references.

Measurement of Eddy Frequency. (H. Blenk, D. Fuchs and F. Liebers, L.F.F., Vol. 12, No. 1, 28/3/35, pp. 38-41.) (22.15/30664 Germany.)

The frequency of eddies shed by cylinders, plates and wing profiles was observed systematically by the pitch of aeolian tones of wires in the wind channel and by visual observation in the water channel. The results are plotted and show, in the case of cylinders, a simple linear relation between wind speed and frequency for a given diameter.

A non-dimensional coefficient is defined and plotted against Reynolds number. The points lie along a unicursal curve with moderate scattering, considering that independent English experiments in air and water are included for comparison.

In the case of plates and wings the angle of incidence affects the results greatly, but if in forming the non-dimensional coefficient, the projected chord in a vertical plane is taken as the characteristic linear dimension, the non-dimensional coefficient does not differ much from that for cylinders.

Five references.

Pressure Measurements in Unsteady Flow. (M. Schwabe, Ing. Arch., Vol. 6, No. 1, Feb., 1935, pp. 34-50.) (22.15/30665 Germany.)

A vertical circular cylinder suspended from above the surface of a water tank to the bottom, is carried along the tank and sets up a relative flow which is not steady. Particles are strewn on the surface and photographed with short time exposures of known length. The distance travelled by a particle gives the mean velocity, successive particles in the same streamline give accelerations along the path, and the curvature of the path gives the accelerations normal to the path.

Except in boundary layer the effect of viscosity is negligible for the times considered and the generalised form of Bernoulli's equation is applicable to each instantaneous streamline. The principles are simple, but evidently great experimental care is required.

Seven photographs of flow are reproduced and examples of reduction are given graphically. It is finally suggested that analytical expressions could be constructed for the motions thus determined.

Five references.

Motion of a Cylindrical Bubble in a Tube. (S. Hattori, Aer. Res. Inst., Tokyo, Report No. 115 (Vol. 9, No. 7), Jan., 1935.) (22.2/30666 Japan.)

A physical theory is given of the relation between surface tension and resistance of the bubble in the tube. Extensive data are given in tables and graphs, showing the position as a nearly linear function of time.

The slopes give the velocities which are shown as functions of the diameter of the tubes. For a critical lower limiting value of the diameter the velocity becomes zero. Measurements were carried out with a number of fluids and the surface tensions are deduced.

Seven references.

Steady Flow in the Boundary Layer Near the Surface of a Cylinder in a Stream. (L. Howarth, R. & M. No. 1632, 1935.) (22.3/30667 Great Britain.)

A critical review is given of methods of forming and solving the flow of a viscous fluid in the transition layer from zero velocity at the solid boundary to approximately " potential " flow at a " sufficient " distance.

The differential equations of viscous fluid motion being non-linear, enormous labour has been expended on obtaining solutions for the simplest cases of steady flow, under various simplifying assumptions. The author's conclusions indicate that, beyond this point, most of the results are negative or trivial. He appears to underrate Thom's work in obtaining particular solutions by successive numerical approximations.

Numerical tables are given for extending the methods of Blasius and Pohlhausen. The flow up to the point where the boundary streamline branches from the boundary has been determined with sufficient accuracy and the position of the branch point itself appears to have been determined to a fair approximation for the critical Reynolds number. Beyond this no mathematical advance has been made.

Various approximate solutions up to the branch point, and the determinations of the branch point itself are compared graphically.

Eight references.

Lift Coefficient of a Thin Elliptic Cylinder. (L. Howarth, Proc. Roy. Soc., Vol. 149A, No. 868, 10/4/35, pp. 558-586.) (22.3/30668 Great Britain.)

Continuing on the lines of R. & M. 1632, the author refers to Joukowski's well known result as an approximate solution of wing lift. (It is, of course, an accurate solution for a wing with a sharp trailing edge in a perfect fluid.) An attempt is made to proceed beyond the determination of the branch points at which the zero streamline (of which the aerofoil surface is part) becomes unstable and leaves the boundary.

References are made to a wide range of effort by Prandtl, Taylor and others to bring turbulent motion within some sort of calculus. Numerical coefficients are taken from experiment so that it is difficult to accept the conclusion that the circulation has been determined theoretically. None the less, this and the preceding paper (Abstract 30667) should be read by anyone who proposes to attack a highly intractable problem.

Measurements on Resistance of Spheres, with Reference to Turbulence and Surface Finish. (S. Hoerner, L.F.F., Vol. 12, No. 1, 28/3/35, pp. 42-54.) (22.3/30669 Germany.)

A brief summary is given of the so-called boundary layer theory in application to spheres and the distribution of pressure is exhibited graphically. The effect of the mounting in the wind channel is discussed at greater length, with numerous illustrations from practice shown graphically. The influence of

turbulence, generated in different ways receives detailed consideration and comparative results are given.

Full-scale experiments were carried out. A photograph shows the mounting of a sphere on an aeroplane and measurements were carried out in a car. The full-scale results are compared with wind channel results.

Finally the effects of surface finish are discussed, and remarkable differences in the critical Reynolds number, distribution of pressure, and coefficients and resistance are shown.

Thirty-two references.

Diversion of a Circular Jet Impinging on the Surface of a Flat Plate. (W. Schach, Ing. Arch., Vol. 6, No. 1, Feb., 1935, pp. 51-59.) (22.35/30670 Germany.)

Reference is made to a previous paper (see Abstract 29934).

Discussion is restricted to normal impact. By superposing a flow with symmetry of rotation on the flow due to a circular line source an expression for the velocity potential is obtained in the form of an integral equation.

The analytical details are worked out fully and numerical results are shown graphically. Finally, streamlines and potential line are drawn. Comparison with experiment shows a slight discrepancy in the form of the free surface.

Three references.

Air Flow in Fan Discharge Ducts. (L. S. Marks, Trans. A.S.M.E., Vol. 56, No. 11, Nov., 1934, pp. 871-878.) (22.4/30671 U.S.A.)

Comparisons of nozzle measurements and pitot tube exploration in a fan discharge duct show discrepancies, which are attributed to failure of pitot tube calibration for a steady flow in application to turbulent flow. Air pulsation and incorrect location of tube at outer edge of jet cause small errors. The principal error is attributed to oblique flow relatively to the pitot tube.

Calibrations of pitot tubes for varying inclinations to the mean flow are given in six diagrams and correction curves are deduced. Examples of distribution of mean velocity are given in six diagrams.

Three references.

Self Checking Notation for Vector Diagrams. (A. C. Walshaw, Phil. Mag., Vol. 19, No. 129, May, 1935, pp. 1027-1032.) (22.4/30672 Great Britain.)

A simple self consistent notation is proposed whereby relative velocities and accelerations exhibited in lettered diagrams may be written down immediately as vector sums and differences.

Pulsating Air Flow. (N. P. Bailey, Trans. A.S.M.E., Vol. 56, No. 10, Oct., 1934, pp. 781-786.) (22.4/30673 U.S.A.)

A description is given, with two sketches, of a portable instrument which is stated to give true average air velocity for any degree of pulsation. Simple mathematical expressions are given for average velocity.

The effects of pulsation in blowers, in engine cylinders and near propellers are shown graphically. (The real difficulties of mathematical physical theory are hardly touched on.)

Turbulence Near the Ground. (W. Schmidt, J. Roy. Aer. Soc., Vol. 39, No. 293, May, 1935, pp. 355-376.) (22.45/30674 Great Britain.)

A rectangular frame carrying from twenty-five to seventy-five light vanes in horizontal rows and staggered columns was exposed to the wind in the open air. The vanes hung from pivots with a lever arm of 10 cm. and carried indicator

plates showing the angle of deflection. The oscillations were highly damped, the plates being light in relation to their surface.

Transverse photographs of the frame recorded the instantaneous deflections of all the plates and taking the deflections as proportional to the square of the local velocities, the latter were plotted as functions of position in the rectangle.

Numerous diagrams of plots are reproduced and exhibit the highly variable motion of the air. The effect of the types of ground surface over which the wind passed before reaching the frame was recorded in this way.

The experiments are a useful systematic contribution to a subject in which mathematical analysis has so far been powerless.

Materials—Elasticity and Plasticity

Magnetostrictive Oscillation of Chladni Plates. (R. C. Colwell and E. A. Bryant, J. Frank. Inst., Vol. 218, No. 6, Dec., 1934, pp. 739-748.) (23/30675 U.S.A.)

A pure nickel rod 10 inches length, $\frac{1}{8}$ inch diameter, was set in vibration by an electro-magnetic coil. Squares and circular plates, mounted on the end of the rod, formed Chladni figures, of which twenty are reproduced. The frequencies were in ratios of small whole numbers to those of the exciting current.

Three references.

The Strength of Materials at Low Temperatures. (W. Schwinning, Z.V.D.I., Vol. 79, No. 2, 12/1/35, pp. 35-40.) (23/30676 Germany.)

Low temperature exerts a beneficial influence on the tensile strength, yield point and fatigue strength under load reversal of steels. The strength under notch tests is considerably reduced. Lowering of the temperature is without apparent effect on either tensile or notch strength of light alloys.

Progress in Applied Mechanics. (Trans. A.S.M.E., Vol. 56, No. 8, Aug., 1934, pp. 563-568.) (23/30677 U.S.A.)

A brief survey of progress is given under group headings:—

Elasticity	27	references.
Strength of materials	8	,,
Plasticity	6	,,
Dynamics	16	,,
Fluid mechanics	56	,,
Thermodynamics	11	,,

Visco-Elasticity. (E. Madelung and S. Flugge, Ann. d. Phys., Vol. 22, No. 3, March, 1935, pp. 209-222.) (23/30678 Germany.)

Linear differential equations with constant coefficients are formed in tensor notation for periodic strain and stress, the coefficients representing the effects of elasticity, viscosity and relaxation in Clerk Maxwell's sense.

A solution is constructed for a sphere in terms of Bessel functions if order $(n+\frac{1}{2})$ and lines of equal amplitude and equal phase are shown in an equatorial section in a segment of 45°, implying quadrantal symmetry.

An analysis is made using optical dispersion and curves are calculated for the case where both relaxation and viscosity terms appear.

The author appears diffident as to the correct interpretation of the results.

Two references.

Finite Strain in Elastic Problems. (B. R. Seth, Phil. Trans. Roy. Soc., Vol. A.234, No. 738, 27/4/35, pp. 231-264.) (23.10/30679 Great Britain.)

The equations of elastic stability are modified to take into account finite strains by the inclusion of terms of higher order than those retained in the ele-

mentary theory. The additional terms are worked out for the torsional couple on a cylinder and numerical values are computed and tabulated.

Eighteen references.

Stress Concentration Produced by Holes and Notches. (A. M. Wahl and R. Beeuwkes, Trans. A.S.M.E., Vol. 56, No. 8, Aug., 1934, pp. 617-625.) (23.10/30680 U.S.A.)

Stress optical methods are applied and the numerical results are shown graphically. Two photographs illustrate the apparatus and seven stress optical photographs are reproduced.

Seventeen references.

Bending of Circular Plates with Large Deflection. (S. Way, Trans. A.S.M.E., Vol. 56, No. 8, Aug., 1934, pp. 627-636.) (23.10/30681 U.S.A.)

The equations of elastic equilibrium are written down and appropriate types of solutions are worked out numerically and shown graphically in tables. Nadai's approximation is sound and differs from the more exact theory by a few per cent. only.

Five references.

Bending Oscillations of a Circular Plate Loaded at its Mean Plane. (K. Federhofer, Ing. Arch., Vol. 6, No. 1, Feb., 1935, pp. 68-74.) (23.10/30682 Germany.)

The equations of elastic deformation are formed and solutions in Bessel functions discussed. Numerical values are tabulated for three cases.

Eleven references.

Micro-Cinema Study of Cutting Metal. (Autom. Ind., Vol. 72, No. 7, 16/2/35, pp. 202-203 and 214.) (23.10/30683 U.S.A.)

A photograph shows the mounting of microscope and cinema-camera on the milling machine.

Micro-photographs are reproduced from the film record, showing details of the yield of the metal under the cutting edge.

Studies in Photo-Elastic Stress Determination. (E. E. Weibel, Trans. A.S.M.E., Vol. 56, No. 8, Aug., 1934, pp. 637-658.) (23.15/30684 U.S.A.)

A description is given of the apparatus and methods of calibration along usual lines. Creep receives lengthy consideration and examples of strain-time characteristics are reproduced. The soap film analogy is used for determining the sum of the principal stresses.

Extensive experimental results are given graphically and ten stress optical photographs are reproduced. A lengthy discussion follows.

Twenty references.

Membrane Analogy Supplementing Photo-Elastic Methods. (J. G. McGivern and H. L. Supper, Trans. A.S.M.E., Vol. 56, No. 8, Aug., 1934, pp. 601-605.) (23.15/30685 U.S.A.)

The sum of the principal stresses in generalised plane strain is fixed by measuring ordinates of a stretched membrane. The mathematical analogy is comparatively simple.

A photograph shows the membrane measuring apparatus and examples of three-dimensional stress surfaces are shown in perspective.

Five references.

Construction of Iso-pachs from Photo-Elastic Observations. (H. P. Neuber, Trans. A.S.M.E., Vol. 56, No. 10, Oct., 1934, pp. 733-737.) (23.15/30686 U.S.A.)

Stone's approximate relations for iso-pachs are rendered exact by inclusion of small terms and a graphical method is developed for point to point plotting.

As an example, the iso-pachs in a stressed angle-plate and the stress field deduced therefrom are shown graphically. (An iso-pach is defined in Coker and Filon's " Treatise " as lines along which the sum of the principal stresses is constant.)

Six references.

Continuous Beams. (J. Hanson, Flight, Vol. 27, No. 1374, 25/4/35, pp. 26-27, and No. 1379, 30/5/35, pp. 32-36.) (23.30/30687 Great Britain.)

A brief historical note is given with reference to the so-called Berry method for spars uniform between nodes. For tapering spars the analysis requires lengthy modifications and a graphical method is proposed.

A numerical example is fully worked out, the necessary graphical work is reproduced and the numerical values taken therefrom are tabulated.

Displacement and Deformation of an Elastic Bar. (E. H. Bateman, Phil. Mag., Vol. 19, No. 129, May, 1935, pp. 1011-1015.) (23.30/30688 Great Britain.)

By equating the work of deformation and the work of displacement under external forces of each unit of an elastic framework, a number of strain stress relations are obtained in a simple and direct manner.

Two references.

Free Elastic Vibrations of Cylinders and Tubes. (L. Posener, Ann. d. Phys., Vol. 22, No. 2, Feb., 1935, pp. 101-128.) (23.30/30689 Germany.)

The elastic equations in polar co-ordinates are written down for thin tubes and a variety of boundary conditions is considered, with different types of vibration. The solutions of special limiting cases by Love-Timpe and Rayleigh are reproduced in elegant form.

The coupling of longitudinal and transverse vibration is exhibited. The vibrations involving expansion and torsion are separable. Love's complete solution for the latter is cited. Pochammer's method of solution for the former is developed at considerable length in terms of Fourier Bessel series.

Buckling of Thin Cylinders under Axial Compression and Bending. (L. H. Donnell, Trans. A.S.M.E., Vol. 56, No. 11, Nov., 1934, pp. 795-806.) (23.30/30690 U.S.A.)

A photograph shows a testing machine designed for the application of combined torsion, bending and compression or tension, on thin circular tubes. When the length is too short to permit Euler's buckling without failure, the buckling load is a function of the yield stress, as well as of the elastic constants.

General differential equations in polar co-ordinates of elastic equilibrium and of strain energy are discussed, with simplifying approximations introduced by different writers and by the author.

Comparisons of ideal theory, with tests on necessarily imperfectly symmetrical specimens show unsystematic discrepancies, but the assumption of a particular form of failure with relatively small strain energy, and the further assumption of maximum shear energy at the nodes of the buckling waves, leads to a semi-empirical approximation which fits the mean experimental curves better than the ideal result. The relative analysis is given in appendices. Extensive test data are given in numerical tables and graphically, and nine photographs show types of buckling failure.

Seven references.

Collapse of Thin Cylindrical Shells under External Pressure. (D. F. Windenburg and C. Trilling, Trans. A.S.M.E., Vol. 56, No. 11, Nov., 1934, pp. 819-825.) (23.30/30691 U.S.A.)

Semi-empirical formulæ, derived from elastic theory by simplifying assumptions, are quoted, and their mutual relations are discussed.

Extensive test data are tabulated numerically. Comparison of formulæ and test results is given graphically. A family of curves gives the relation between thickness/diameter, length/diameter and the number of lobes in tube which collapses under uniform radial and axial pressure.

Twenty-two references.

Buckling of Flat Curved Bars and Slightly Curved Plates. (S. Timoshenko, J. of Applied Mechanics, Vol. 2, No. 1, March, 1935, pp. A.17-A.20.) (23.30/30692 U.S.A.)

Euler's buckling formulæ is given in Perry's approximate form and the stability criterion given as an integral equation becomes immediately integrable. The numerical consequences are discussed graphically and the results extended to the buckling of bimetal strips.

Sheet Strip with Beaded Circular Holes Under Shear. (K. Schüssler, L.F.F., Vol. 11, No. 3, 18/8/34, pp. 74-85.) (23.30/30693 Germany.)

Tests at the Aachen Aerodynamical Institute on beaded lightening holes show that lightening may be consistent with actual increase in strength. Photographs and sketches show strip with beaded lightening holes before and after buckling.

The results are given in a table for 78 test pieces and graphical representation shows the relations between load, spacing, size of beading, thickness and width. Each width and thickness of strip had an appropriate spacing and beading of lightening holes.

Seven references.

Buckling Strength of Cylindrical Shell with Stiffeners Under Pressure. (Dji-Djuan Dschou, L.F.F., Vol. 11, No. 8, 6/2/35, pp. 223-234.) (23.30/30694 Germany.)

Approximate formulæ are developed and the functions involved in the solution are shown graphically in five diagrams.

General conditions for the critical buckling load are given by three simultaneous differential equations which express the equality of the buckling loads to the resultants of the internal stresses of the strained shell. Eliminating the undetermined quantities a determinant of the third order, equated to zero, gives the criterion for buckling. The determinantal equation is reduced to a convenient algebraic equation of general applicability.

Numerical examples are given.

Five references.

Increasing the Fatigue Strength of Structures. (H. Ude, Z.V.D.I., Vol. 79, No. 2, 12/1/35, pp. 47-53.) (23.40/30695 Germany.)

The symposium of papers deals largely with bearing metals and corrosion. In the case of engine crankshaft bearings, it is difficult to avoid deformation in the crankcase with consequent unequal bearing loads. In one case stiffening the crankcase webs caused the bearing to fail, since it could no longer follow the deformations.

Copper lead alloys are suitable for bearings exposed to sudden shocks (Diesel engines). In another case sea water corrosion of " V2 An " steel was considerably reduced by mechanised surface pressure treatment.

Experiments on Buckling of Thin Walls. (F. J. Bridget and others, Trans. A.S.M.E., Vol. 56, No. 8, Aug., 1934, pp. 569-578.) (23.40/30696 U.S.A.)

Test figures for circular cylinders are given and examples of buckling are shown in photographs. Test figures for L struts are given. Up to a certain width of side plate, Euler's formula for columns applies, beyond this width, which is sharply defined, the buckling is of the flat plate type with corrugations. On plotting the normal stress against shear stress on logarithmic scale, approximately linear characteristics are obtained, with rather heavy scattering in some cases.

Eleven references.

Miscellaneous

Research in the Chemical Industry. (H. G. Grimm, L.F.F., Vol. 11, No. 7, 14/1/35, pp. 189-191.) (O.G./30697 Germany.)

The author is connected with the I.G. Farbenindustrie and describes the interrelation of educational establishments, societies, research institutions and works laboratories on the one hand and the projection, protection by patents, manufacture and marketing of products.

A statistical table shows that while total exports have fallen to one-third from 1929-1933, chemical exports have fallen only to one-half, and were about $14\frac{1}{2}$ per cent. of the total exports in 1933.

ABSTRACTS OF PATENT SPECIFICATIONS

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

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Aerodromes

437,794. *Improved Wind-Direction Indicator for Aerodromes and Analogous Situations.* Hart, E. P., The Girls' High School, Pretoria, Transvaal. Dated April 26th, 1935. No. 12,581.

This indicator consists of a number of radial illuminants symmetrically extending from a common centre and an arrow-shaped or similar illuminant at the outer end of each radial illuminant. There is also a group of illuminants arranged in the form of a ring round the common centre and adopted to project light rays inwardly. Reference is made to specification No. 421,876.

Aerodynamics

437,885. *Improvements in or relating to the Streamline Formation of Bodies for Land Vehicles and Aircraft.* Tennant, W. J., 111/112, Hatton Garden, London, E.C.1. Dated March 1st, 1934. No. 6,605.

In the case of bodies intended for aircraft or motor vehicles it is pointed out that owing to practical considerations, such as the necessity of providing view for the driver and also the providing of mudguards, etc., that the optimum streamline body cannot be used. It is proposed, therefore, to reduce the resistance of such imperfectly streamlined vehicles by the delivery of pressure air at the points of disturbance, the air being tapped through conduits opening at zones of pressure directly on the surface of the body.

438,037. *Improvements relating to the Propulsion of Aircraft.* The Federated Engineers, Ltd., 3, Central Buildings, Westminster, London, S.W.1, and Brackenbury, E. W., 13, Victoria Street, Westminster, London, S.W.1. Dated May 9th, 1934. No. 14,007.

It is stated that when a fluid stream is directed substantially radially from the surface of a body it not only causes a tractive effort, but also clings to the

surface of the body, hence energising the boundary layer and reducing the resistance. It is therefore proposed to construct an aeroplane having a motor-driven blower collecting air from an inlet facing forward and delivering this air by means of internal ducts so that it emerges radially from the front of the fuselage and also from the leading edge of the main plane.

Aeroplanes—Construction

430,662. *Improvements in or relating to Pusher Airscrew Aeroplanes.* Baynes, L. E., of E. D. Abbott, Ltd., Farnham, Surrey. Dated Dec. 22nd, 1933. No. 36,112.

The aeroplane described is a high wing monoplane in which the wing is placed on top of a normal fuselage. The nose of the wing is faired into an enclosed cabin forward and the engine is carried on a structure above the wing. The engine is arranged as a pusher, the propeller being placed at about the trailing edge of the wing. The arrangement therefore permits the propeller to be arranged lower in the aircraft than is usual on such machines and this is claimed as the advantage of the arrangement.

430,331. *Improvements in or relating to the Construction of Aeroplanes.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Hollis-Williams, D. L., Hillside, Swakeley's Road, Ickenham, Middlesex. Dated Oct. 23rd, 1932. No. 36,474.

In order to combine the advantages of high and low wing monoplanes it is proposed to construct a low wing monoplane with the centre section arched upwards, so that the wing may meet the upper part of the fuselage. Constructional arrangements are described and the arrangement may be applied to the lower wing of biplanes.

428,225. *Improvements in Metal Framework for Aircraft.* A.T.S. Co., Ltd., and Wylie, H. N., both of 3/4, Clement's Inn, Strand, W.C.2.

In order to stiffen metal covering for the wings, fuselages, hulls, etc., of aircraft, it is proposed to attach to the covering a longitudinal member spaced from the covering and braced to it by diagonal bracing, the widths of the longitudinal and of the bracing respectively being less than the depth of the member.

438,327. *An Improved Method of Covering Aircraft Components.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Pearce, H. L., 103, Studland Road, Hanwell, London, W.7. Dated April 25th, 1935. No. 12,477.

For the purpose of covering aircraft planes with fabric it is proposed to wind the upper and lower booms of the ribs with fabric to which the covering fabric is sewn together with a reinforcing strip. In order that the seams may have a smooth surface they are then covered with a narrow strip of cellulose acetate reinforced with fabric and the wing is then treated with solvent varnish.

Aeroplanes—General

430,421. *Improvements relating to Illuminating Devices for Aircraft.* Harley, M. C., The Red House, Cranford, Middlesex. Dated Dec. 14th, 1933. No. 35,258.

The lamp proposed has a parabolic reflector in front of which a special diffusing arrangement causes a spread of the beam, while the lower half of the beam is allowed to emerge substantially parallel. The lamp is arranged so that it can be folded into the aeroplane, and also so that its inclination relative to the aeroplane can be controlled by the pilot in flight. The mechanism for this is

described and consists of a quadrant designed for rigidity operated by means of a Bowden wire control.

Aircraft—General

437,787. *Propeller Drive for Wingless Aircraft.* Paul Merz, Luzernerring 136, Bale, Switzerland. Convention date (Switzerland), March 13th, 1934.

This specification describes an aircraft of rectangular plan form having a section resembling an aerofoil arranged to be driven, supported and stabilised by means of rowing propellers. These latter resemble, approximately, normal propellers, and are arranged in pairs on opposite sides of the aircraft on vertical axes so that half of the propeller works in a lateral cell in the body. The other half is exposed on the outside of the body and it is this part which is stated to act as claimed above. Blade incidence is adjustable.

436,099. *Improvements in or relating to Aircraft and Other Vehicles and the Like.* Ramsbottom, J. E., Lockspeiser, B., and Stewart, C. J., all of the Royal Aircraft Establishment, South Farnborough, Hants. Dated April 7th, 1934. No. 10,549.

This specification deals with de-icers of the type in which a liquid known to lower the freezing point of water, such as ethylene glycol, is forced by pressure through a permeable covering situated on the leading edge of the wing, or in other positions that it is desirable to protect. The liquid under pressure may be carried in a pierced rubber tube, and so distributed within the permeable covering. A similar method of protection is described as suitable for de-icing propellers and their hubs or spinners.

Airscrews

438,317. *Improvements in or relating to Means for Actuating the Rotatable Blades of Blade Wheels.* Voith, W., Voith, H., and Voith, H., Heidenheim, ander Brenz, Wurtemberg, Germany. Convention date (Germany), March 26th, 1934.

This specification is concerned with rotary propellers, described as blade wheels, in which the blade axes are approximately paralled to the axes of the wheel. In order to control these blades it is proposed to use a member which is centrally located when the blade inclination is zero, but is eccentrically adjustable and which revolves with the blade wheel, is pivotally connected for each blade a rod which is longitudinally slidable in an oscillatable guide the pivotable point of which is fixedly located upon the wheel and from which the augular movement of the blade is obtained.

438,332. *Improvement relating to Aircraft.* Houston, R. G., 9, Amity Street, Dingle, Liverpool, 8. Dated May 10th, 1935. No. 13,776.

This invention relates to aircraft and its object is the provision of a device which surrounds the propeller of the craft and mechanically controls the air current both in front and at the rear of the propeller for the purpose of minimising drone, cooling of the aero engine and speed accelerations and retardations.

438,295. *Improvements in or relating to Cylindrical Propellers.* Mellersh-Jackson, L., of Haseltine, Lake and Co., 28, Southampton Buildings, Chancery Lane, London, W.C.2. Dated Dec. 6th, 1934. No. 35,082.

The type of propeller proposed consists of a box of approximately circular section having a number of slots in its circumference through which project a number of blades. As, in the interior of the box, the blades are attached to an eccentric centre, the blades will be caused to project from or be withdrawn into

the box on rotation and can be used for propulsion. The eccentric centre can be adjusted so as to modify the direction of the action of the propeller and the circular box can be made watertight.

Autogiros

435,818. *Improvements in or relating to Helicopter and Rotating Wing Aircraft.* Coats, A. G., Gloucester House, Park Lane, London, and Hafner, R., Manthergasse 47, Vienna, 13, Austria. Dated March 29th, 1934. No. 9,867.

In the case of rotors with flapping blades it is stated to be desirable that the blades should be pivoted in such a way that the flapping axes intersect one another and also the axis of rotation of the hub member. In order to effect this in the case of a three-bladed rotor, the blade arms are attached to a fork with unequal projections which lie within and without each other alternately, and which bear on pins extending radially, the pins being supported by an external ring. The blades may be provided with means for varying their inclination controlled by means of radius rods operated by means of a spider arranged about the hub.

Bombs and Ballistics

438,300. *An Improved Bomb-Aimer's Windscreen.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Ebbutt, C. G. W., Wallingbourne, Manor Park Drive, North Harrow, Middlesex. Dated Dec. 14th, 1934. No. 35,951.

In order to protect the bomber from air currents he is provided with a windscreen formed by two or more pieces of transparent material arranged so as to have an open slot between them. The whole arrangement is mounted on a rotatable frame, rotatable by the bomber and so arranged that the frame may be rotated to a position where the slot is covered by a shield, preventing air from entering the cockpit.

436,069. *Improvements in or relating to Gun Mountings.* Boulton and Paul, Ltd., Riverside Works, Norwich, Norfolk; North, J. D., Hill House, Eaton Hill, Norwich, Norfolk; and Hughes, H. A., Westfield, Plumstead Road, Norwich, Norfolk. Dated Feb. 2nd, 1933. No. 3,204.

The gun mounting described consists of a revolving turret partially embedded in the nose of an aeroplane fuselage. It is entirely covered with a transparent material, but has a vertical slot to permit the gun to be fired upwards or downwards. Traversing is done by moving the gun laterally, which action opens and closes valves connected with a compressed air motor turning the whole turret, so that the turret follows the gun. Types of driving motor and methods of operation are described and the driving mechanism may be used in conjunction with cylinders containing oil.

Control of Aircraft

438,020. *Apparatus for Automatically Regulating the Course or Speed of an Aircraft.* Siemens-Apparate und Maschinen-Gesellschaft Mit Beschraenkter Haftung, 4, Askanischer Platz, Berlin, S.W.11, Germany. Convention date (Germany), Feb. 3rd, 1933.

It is proposed to regulate the course or speed of an aircraft by means of an arrangement for measuring deviations of the craft from the desired course or speed and a primary piston moved in accordance with the deviations measured thereby, the movements of such primary piston being damped so as to take place at a speed proportional to the rate of change of such deviations, thereby setting up a fluid pressure proportional to such rate of change, the pressure being employed to control the movements of a secondary piston. The movements of

the two pistons are applied jointly to control a servo motor operating on the appropriate control surface of the craft. There may be a further control proportional to the acceleration with which the deviations change.

438,021. *Apparatus for Automatically Regulating the Attitude, Course or Speed of an Aircraft.* Siemens-Apparate und Maschinen-Gesellschaft Mit Beschraenkter Haftung, 4, Askanischer Platz, Berlin, S.W.11, Germany. Convention date (Germany), Dec. 19th, 1933.

This specification is similar in many ways to 438,020 (above), but claims that the means for measuring the angular velocity of the craft about the axis comprises a spring enclosed gyroscope, and also an arrangement by which one of the pistons contains the cylinder enclosing the other piston.

431,648. *Improvements in or relating to Control Mechanism for Aeroplanes.* Baynes, 144, Cromwell Road, London, S.W.7. Dated Jan., 1934. No. 1,193.

In order to obviate the use of the rudder bar on aeroplanes it is proposed to use a control lever of the normal type, but carrying on its upper end two concentric control wheels mounted one behind the other and operating the rudder and ailerons respectively. With this arrangement the rudder and ailerons can be operated apart by using one hand on each wheel, or together by gripping both wheels at once. Fore and aft movement of the stick operates the elevators as usual.

431,328. *Improvements in Piloting Controls for Aircraft.* Bendix Aviation Corporation, 105, West Adams Street, Chicago, Illinois, U.S.A. Convention date (U.S.A.), Oct. 6th, 1932.

It is proposed to combine the action of manual and automatic control on the controls of an aeroplane so that such control surfaces as are rarely operated in flight are operated automatically, whilst those controls which are frequently operated in flight may at any time be controlled manually in addition to the automatic control. The preferable arrangement is that the rudder and elevator should be so arranged that manual operation cannot be used unless the automatic control is cut out, while in the case of ailerons manual control may be superimposed on the automatic.

435,888. *Automatic Aero-Dynamic Stabiliser for Aeroplanes.* Bembery, O. E., 28, Rue Emile Meniev, Paris (Seine), France. Convention dates (France), Oct. 12th, 1933, and July 4th, 1934.

This specification describes a modification to an arrangement described in Patent No. 422,493. The stabilisation is carried out by means of two wind vanes which are mounted near the wing tips of the aircraft. These are so connected by a link and lever motion that when they come into action owing to the inclination of the aeroplane the effect of one of them is large and, of the other, small. The movement of the vanes is coupled to the controls. The vanes may consist of a cruciform arrangement of planes connected by a rod to a similar tail. The planes may differ in angle from the tail, and the tail may be weighted.

Engines

431,687. *Improvements in and relating to Motor Driven Propeller Units.* Scott, B. D., Camp, Miserden, nr. Stroud, Gloucestershire. Dated Jan. 8th, 1934. No. 689.

In order to avoid the torque reaction on aircraft it is proposed to use two concentrically mounted propellers running in opposite directions driven by a special type of internal combustion engine. This engine has multiple cylinders mounted so that each pair of cylinders has a common combustion chamber, and there are two crankshafts turning in opposite directions. From this engine the

propellers are driven by gearing. Engine auxiliaries are driven by a coupling rod device and the exhaust gas operates an air blower, air from which may be used for cooling or supercharging.

430,443. *Improvements relating to the Cooling of Air-Cooled Radial Cylinder Engines on Aircraft.* Siemens and Halske Aktien-Gesellschaft, Berlin-Siemensstadt. Convention date (Germany), Jan. 28th, 1933.

In the case of radial air-cooled engines fitted with a cowl of the Townend type it is proposed to conduct the cooling air to each cylinder through a separate passage, the air being conducted round each cylinder through a jacket. The openings in the front of the cowling are rectangular in section, arranged with the major axis radial, the openings in the rear of the cowling are also rectangular, but the major axis is circumferential, the section of the passage changing gradually from one to the other. The passages are so proportional that the cooling air has the same velocity at the entry and outlet as the outside air, allowance being made for temperature increase. It is claimed that the arrangement prevents turbulence.

435,879. *Flexible Mountings for Aircraft Power Units.* Armstrong-Siddeley Motors, Ltd., Wylie, H. N., and Gay, A. R. B., all of Armstrong-Siddeley Works, Park Side, Coventry. Dated May 22nd, 1934. No. 15,241.

This specification describes a method of flexibly mounting aircraft engines of the radial type. It is proposed to attach the engine to a support which is of built up box section, the circular engine mount carrying a flanged ring in which rubber is fitted so that the engine is supported on a spigotted rubber mount. The bolts are carried through clearance holes in the flange and have rubber bushings to absorb torque. In certain cases springs may be substituted for the rubber and a case is described where flexibility between the bolt and the mounting is secured by means of freely turning steel rollers. Modifications of the arrangement are described.

Flying Boats

435,712. *Improvements in and relating to Lateral Stabilising Fins for Flying Boats.* Saunders-Roe, Ltd., Knowler, H., and Farrow, J. R., all of Columbine Works, Medina Road, East Cowes. Dated April 21st, 1934. No. 12,056.

It is proposed to arrange stabilising stub wings for flying boats so that the leading edge of the stub wing lies approximately parallel to the hull wave, the precise angle, stated to be about 15°, to be ascertained in a tank test on a model hull. The fins are to be of streamline section and are to have little or no positive angle of incidence when the machine is in flight at the usual cruising speed. The trailing edge of the stub wing may be parallel to the leading edge, or may have other forms and the wing tips may be rounded.

Helicopters

437,910. *Improvements in or relating to Aircraft.* Oehmichen, E. E., Rue des Graviers, Valentigney (Doules Department), France. Convention dates (France), Oct. 23rd, 1933, and Oct. 31st, 1933.

This invention is claimed to describe a navigation apparatus with static stabilisation and high coefficient of security, which is capable of effecting vertical, horizontal or inclined flight. The static stabilisation and the security are obtained by providing the apparatus with one or more light wing envelopes in the form of tapered bodies of great penetration, rigid or not, filled with air and surmounting a motor propelling mechanism to which it is attached indeformably, the centre of volume of this wing envelope or of the whole of the wing envelopes being

above the general centre of gravity of the apparatus and on the vertical of this same centre when the apparatus is in normal flight of translation.

438,111. *Improvements in Rotary Wings for Aircraft.* Asboth, A., Nurnburger-strasse 53/55, Berlin, W.50, Germany. Dated March 12th, 1934. No. 7,746.

In the case of rotary wing machines it is usual to hinge the blades of the lifting rotor in the neighbourhood of the hub. Owing to certain stated difficulties it is proposed to construct these blades in several parts, the parts being connected by semi-rigid flexible elastic or resilient couplings.

Jet Propulsion

431,646. *Improvements in or relating to the Propulsion of Solid Bodies in Fluid Media.* Coanda, H., 10, Rue Bardin, Clichy (Seine). Dated Jan. 8th, 1934. No. 682/34.

This specification relates to a method of jet propulsion in which the jet of air may be produced either by a motor-driven fan or a flame. In the case of the flame, air is introduced and is allowed to expand in a tapered chamber. On issuing from this chamber it is deflected backwards by an aerofoil shaped member. Modifications of the apertures for air entry are described and in the position of the aerofoil. The arrangements for the fan-produced jet are similar.

Miscellaneous

438,353. *Improvements in Floating Stations.* Creed, F. G., 38, Outram Road, Addiscombe, Croydon. Dated March 15th, 1934. No. 8,238.

It is proposed to construct floating platforms for aircraft in either T or isosceles triangle form, each supported by three cylindrical floats arranged vertically. Extensions to the platform are hinged to the main platform, the other end being supported by a similar float.

Undercarriages

438,165. *Shock Absorbing Means for the Undercarriages of Aircraft.* Elektron-metall G.M.B.H., Stuttgart-Bad, Connstatl, Germany. Convention date (Germany), Dec. 16th, 1933.

In order to absorb the shock of an aeroplane alighting it is proposed to use the resilient properties of tubes strained in torsion. The shock is transmitted to one end of the tube via a crank, the other end of the tube being fixed. The tube may lie along the fuselage or the wing or may form a portion of the under-carriage. Multiple torsion tubes may be used, arrangements being made for them to come into action one after another by means of crank elements normally clear of the operating member, but which contact when the previous torsion members are under sufficient stress.

438,296. *Improvements relating to Retractable Aircraft Undercarriages.* Dowty, G. H., 17, Lansdown Crescent, Cheltenham. Dated Dec. 7th, 1934. No. 35,231.

This specification describes a retractable undercarriage which is, normally, intended to retract the wheel forwards. There is a hinge on the front spar of the aeroplane wing which carries a vertical retracting jack which extends upwards. The lower projection of the jack carries a normal shock absorbing apparatus and the wheel. There is also a diagonal strut from a position near the wheel to the rear of the wing. When the jack is operated to retract the lower portion of this strut swings upwards in a radius, the jack at the same time shortening the apparatus so that in the retracted position the jack and the retracting apparatus is horizontal. The jack may be used as part of the shock absorbing apparatus.

THE FUNDAMENTALS OF BOUNDARY LAYER THEORY, WITH SOME APPLICATIONS TO AIRCRAFT

BY

H. LEADERMAN, B.A., B.Sc.(Eng.)

A Paper read before the Students' Section on December 5th, 1935.

In the chair: Professor L. BAIRSTOW, C.B.E., F.R.S. F.R.Ae.S.

PART I.—PHYSICAL PRINCIPLES

1. Introduction and Scope of Paper

The recently issued Report of the Aeronautical Research Committee draws attention to the fact that much work, apparently of academic interest only, is now of direct practical utility. In particular, the theories of the boundary layer and of turbulence, though admittedly very incomplete and uncertain and lacking a secure scientific foundation, have been developed to the stage in which they can be applied to explain and predict the behaviour of aircraft, and to show how aircraft may be improved. The physical structure of the boundary layer will be described, and the methods by which the problems have been attacked mathematically to get useful results and to check the theories.

In conclusion, the theory of the boundary layer will be applied to the calculation of the drag of an airship or aeroplane fuselage under full-scale conditions, and to an explanation of the behaviour and performance of different types of aerofoils.

2. Historical (to 1904)

For many years, hydraulic engineers had required information concerning the resistance of pipes to the flow of water, and in recent times, aircraft engineers have required reliable information as to the resistance of aircraft. It was realised that, except at very high speeds, air could be regarded as incompressible, and therefore the solution of the problem of the flow of water in pipes could be associated with the solution of the problem of the drag of aircraft. Though the mathematical equations of the motion of a viscous incompressible fluid were formulated over a century ago, yet, owing to their complexity and to an incomplete understanding of the mechanism of fluid flow, solutions were obtained, with a few exceptions only for the flows through pipes at very low speeds, and of the drags of bodies moving through fluids at very small Reynolds number. Consequently, hydraulic engineers at that time had to resort to empirically determined resistance coefficients; these coefficients suffered the defect of being constant over only a very limited range of Reynolds number.

3. The Concept of the Boundary Layer

Such was the state of affairs in 1904, when Prandtl presented his theory of the boundary layer. The flow of fluid of small viscosity around a streamline body, except in a narrow region in the immediate vicinity of the body, appeared to correspond to the potential flow, *i.e.*, the flow of an inviscid fluid. It was known that the fluid in contact with the body is at rest relative to the body, and that consequently across this narrow region, which he called the "boundary layer," there is a very steep velocity gradient.

Even though the coefficient of viscosity is small for fluids such as air and water, yet the magnitude of this velocity gradient is sufficient to give rise to viscous forces comparable to the inertia forces; and they must consequently be accounted for in the equations of motion for the fluid in the boundary layer.

Outside the boundary layer, the transverse velocity gradients, and hence the viscous forces, are negligible. The resistance of a body moving through a fluid of low viscosity is dependent therefore on the behaviour of the fluid in the boundary layer.

4. *Structure of the Boundary Layer: Laminar Flow*

At the time that the boundary layer theory was formulated, it was thought that, in general, the flow pattern in the boundary layer is always of a streamline nature; this was called " laminar flow." Any fluctuations of position that are present are too small to detect, and must be of the order of the mean free path of the molecules.

Now let us consider a minute sphere of fluid in the incident stream. This sphere may be acted upon by direct stresses, and by tangential (shear) stresses. The longitudinal and shear strains resulting from these stresses are equivalent to three mutually perpendicular principal strains. Thus the sphere becomes an ellipsoid, and the axes of the ellipsoid are the three principal axes of strain. The effect of the viscous forces is to give this particle a rotation or " vorticity "; and a measure of its moment of momentum is given by twice the angular velocity about the axis of rotation. Outside the boundary layer, the effect of viscosity is negligible, and the axes of the ellipsoid always point in the same direction. We say that the main flow is " irrotational," and that the vorticity is confined to the boundary layer and the wake.

5. *Structure: Transition, Turbulence*

If we consider a two-dimensional boundary layer, then the axis of rotation of minute elements is normal to the plane of flow. If a rotating particle in the laminar boundary layer undergoes a displacement in the plane of flow, it behaves as an elementary wing, and exerts a force at right angles to the direction of displacement. If this force increases the original displacement, the particular distribution of vorticity is unstable, and transition to turbulent flow occurs. In the turbulent boundary layer, comparatively large particles, rotating as a whole, pursue erratic paths through the boundary layer.

In formulating a theory of turbulence, we may consider the fluctuating motion of the particles as giving rise to an interchange of moment of momentum or vorticity; or on the other hand, we might consider the mechanism as being equivalent to an interchange of linear momentum. We shall see later how Taylor and Prandtl developed these ideas.

Part II.—Theory of the Laminar Boundary Layer

1. *Derivation and Reduction of Equations*

The equations of motion of a viscous incompressible fluid state that the mass-acceleration of a particle in a given direction is equal to the resultant of the pressure and viscous forces in that direction. These are the Navier-Stokes Equations of Motion.[1] In addition, we have the equation of continuity, which

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[1] The Navier-Stokes Equations are :—

$$Du/Dt = \partial u/\partial t + u(\partial u/\partial x) + v(\partial u/\partial y) + w(\partial u/\partial z) = -(1/\rho)\,\partial p/\partial x + \nabla^2 u(\mu/\rho)$$

(and two similar equations for Dv/Dt and Dw/Dt)

where $\nabla^2 = (\partial^2/\partial x^2 + \partial^2/\partial y^2 + \partial^2/\partial z^2)$

The Equation of Continuity is given by :—

$$\partial u/\partial x + \partial v/\partial y + \partial w/\partial z = 0$$

The equations of a thin plane boundary layer become :—

$$-(1/\rho)\,\partial p/\partial y = 0,\quad u(\partial u/\partial x) + v(\partial u/\partial y) = -(1/\rho)\,\partial p/\partial x + (\mu/\rho)\,(\partial^2 u/\partial y^2)$$

expresses the fact that the fluid is incompressible, and that fluid is neither created nor destroyed.

These general equations are insoluble, due to the fact that the unknown velocities and their derivatives occur multiplied by each other. Now the viscous term may be neglected outside the boundary layer. If the boundary layer is thin compared to its length, then the terms in the equations of motion are of different magnitudes; a first simplification consists in dropping the terms of lower order. The equations then obtained indicate that when the boundary layer is thin, the pressure across it is uniform and equal to that in the main stream outside; since the displacement of the potential flow is small, the pressure through the boundary layer at any point is that which can be calculated on the inviscid fluid theory.

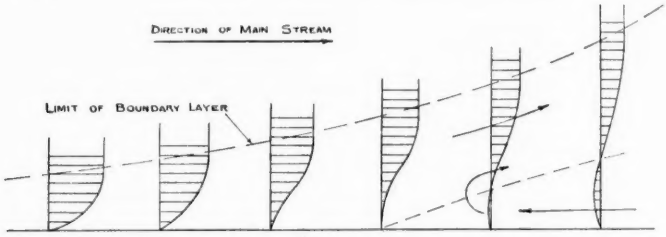
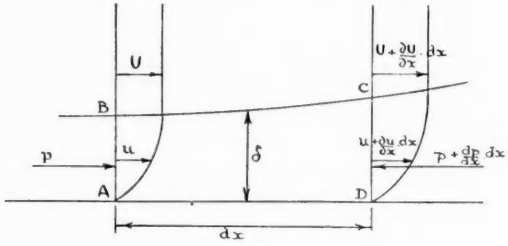


FIG. 1.

Diagram illustrating separation of laminar boundary layer.

2. *Separation (Fig. 1)*

When the flow over a surface meets an adverse pressure gradient, the boundary layer, which is already moving more slowly than the main stream, undergoes a further retardation due to the adverse pressure. After a very short distance, the effect of this adverse pressure gradient is to cause the slower particles in the boundary layer to move in the opposite direction to the main



Net loss of momentum through AB and $CD = dx\,(d/dx)\int_0^\delta \rho u^2 dy$.

Net loss of momentum through $BC = \rho U v dx = -\rho U dx \int_0^\delta (\partial u/\partial x)\,dy$.

Resulting force $= \delta\,(dp/dx)\,.\,dx + \tau_0 dx$ and $\tau_0 = \mu\,(\partial u/\partial y)_{y=0}$.

$$\therefore\ \rho U^2\,(d/dx)\int_0^\delta (u/U)^2\,dy - \rho U^2\,(d/dx)\int_0^\delta (u/U)\,dy = -\delta\,(dp/dx) - \tau_0.$$

FIG. 2.

The momentum theorem for steady flow.

stream. This produces a rapid thickening of the boundary layer, and results in the main flow separating from the contour of the body. The alteration in flow pattern causes a reduction of pressure on the rear portion of the body; therefore in the case of a bluff body, viscosity, though in itself producing only a small skin friction drag, may profoundly alter the flow pattern so as to set up a large pressure or form drag. The phenomenon of separation therefore requires further investigation.

3. *Solution of the Boundary Layer Equations*

Our object in solving the boundary layer equations is twofold: first, to find the drag of a flat plate in a parallel stream for comparison purposes later on; and secondly, to calculate the position where separation is likely to take place. In both cases, it is necessary to determine the velocity distribution in the boundary layer. There are two methods of solving the problem. The first method aims at finding a velocity distribution which satisfies the equations of motion for every particle in the boundary layer. This usually leads to long methods involving much arithmetic. The second method is an approximate method; it aims at

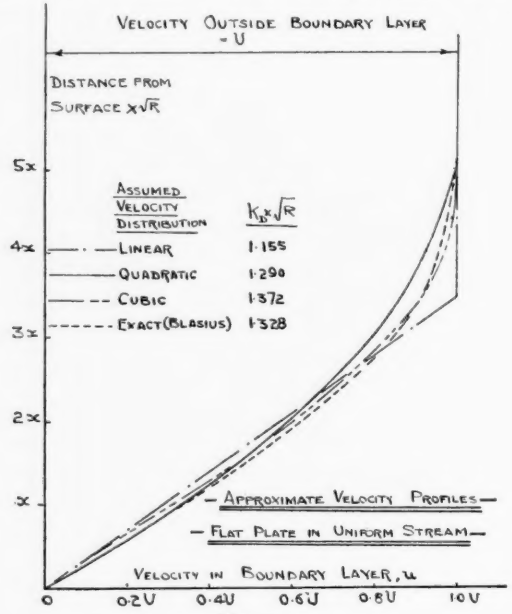


FIG. 3.

Laminar skin friction of a flat plate.

extracting a velocity profile which satisfies the more important boundary conditions and the momentum requirements. If the velocity profile is reasonable, the results obtained differ by only a small amount from the exact results, and are arrived at with much less expenditure of effort.

Application of the Momentum Theorem

The Momentum Theorem of von Kármán states that the loss of momentum of the fluid in passing through a short length of boundary layer is equal to the work done against wall friction and external pressure (Fig. 2).

At any section of the boundary layer, the total drag on the upstream portion of the surface is a function of the momentum lost by the retarded fluid at that section, *i.e.*, of the shape of the profile and the thickness of the boundary layer at that section. Let us call this function α. The *local* drag coefficient is a function of the slope of the velocity profile at the surface; let us call this β. Then we have a relation between α and β involving two unknowns, the velocity distribution, and the boundary layer thickness. If we adopt a simple algebraic function to express the shape of the velocity profile, and make the coefficients fit the terminal conditions, the problem is then soluble, since we then have only one unknown in the equation.

Laminar Skin Friction of a Flat Plate

When we apply this approximate method to calculate the laminar skin friction of a flat plate, it is seen that neither the velocity profiles nor the drag coefficients differ very much from the exact ones calculated by the long method (Fig. 3).

The mathematical theory of separation shows that a laminar boundary layer has only a very small power to resist separation under an adverse pressure gradient. Since the drag of a turbulent flow is less than that due to separation of laminar flow, transition to turbulent flow over the rear portion of a fuselage or upper wing surface must take place to avoid separation.

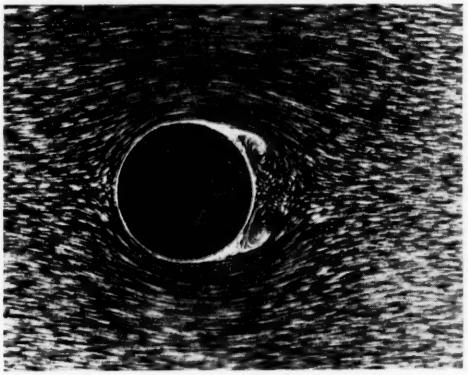


FIG. 4.

Commencement of separation of flow from circular cylinder.

Separation of Laminar Boundary Layer from Circular Cylinder

Separation occurs at 81° from the front stagnation point, thus the boundary layer which has been under an accelerating flow over 72° of the circumference is able to survive only 9° of adverse pressure gradient. Fig. 4 shows the flow shortly after commencement of motion. The theoretical streamlines agree very well with the experimentally observed streamlines, and this may be regarded as a check on the validity of our approximations.

PART III.—TURBULENCE

1. (a) Introduction

The turbulence problem is one of the most important and difficult problems of fluid mechanics. It is required in the theory of streamlining, and is essential for a full understanding of the behaviour of aerofoils. Knowledge of turbulence theory is required by hydraulic power engineers, and by engineers interested in con-

veying water, oil, or natural gas through pipe-lines over long distances. Turbulence also enters into the solution of problems connected with meteorology and internal combustion engine design.

It was only to be expected, therefore, that the first attacks on the problem were made by men with the outlook and training of an engineer: Osborne Reynolds, Prandtl, and von Kármán. Such attacks were, so to speak, flanking attacks and were of a semi-empirical nature; they attempted to link up results obtained over a very large range of scale with a theory of turbulent motion. This method has yielded results of great practical use. A direct frontal attack is also being made, but so far has yielded no scientific basis to connect together the enormous amount of experimental material.

Since turbulence occurs not only in the boundary layers, but also in the wakes of bodies and at the mixing of two fluid streams, the experimental field for checking our theories is very wide.

TABLE OF THE THEORIES OF TURBULENT INTERCHANGE
(AFTER TH. VON KARMAN).

O. Reynolds	Apparent stresses defined by transfer of momentum by fluctuations.	$u=\bar{u}+u'$, etc. Components of apparent stresses: $\sigma_x=-\rho\overline{u'^2}$, $\tau_{xy}=-\rho\overline{u'v'}$ $\sigma_y=-\rho\overline{v'^2}$, $\tau_{yz}=-\rho\overline{v'w'}$ $\sigma_z=-\rho\overline{w'^2}$, $\tau_{zx}=-\rho\overline{w'u'}$
L. Prandtl	Momentum transferred by fluid masses under conservation of momentum in direction of mean flow.	l = mixing length $\bar{u}+u'=\bar{u}+l\,d\bar{u}/dy$ $\therefore\ \tau=\rho l\overline{v'}\,d\bar{u}/dy$ $\therefore\ -\partial p/\partial x=\partial\tau/\partial y=\rho(d/dy)\,(l\overline{v'}\,d\bar{u}/dy)$
Th. von Kármán	Similarity hypothesis: Mixing process similar everywhere, differing only in scales of length and time.	u', v', w', $\propto l\,d\bar{u}/dy$ $l=\kappa\,\lvert(d\bar{u}/dy)/(d^2\bar{u}/dy^2)\rvert$ where $\kappa\simeq 0.4$ $\tau=\rho l^2\,(d\bar{u}/dy)^2=\rho\kappa^2\,(d\bar{u}/dy)^4/(d^2\bar{u}/dy^2)^2$
G. I. Taylor	Vorticity transferred under conservation of vorticity.	Boundary layer: $-\partial p/\partial x=\partial\tau/\partial y=\rho\,(d/dy)\,(l\overline{v'}\,d\bar{u}/dy)$ Wake: $-\partial p/\partial x=\partial\tau/\partial y=\rho l\overline{v'}\,d^2\bar{u}/dy^2$

(b) Momentum Transfer: Reynolds

These are the problems we have to solve. What is the drag of a turbulent boundary layer, and how does it vary with scale? What is the effect of curvature and pressure gradient on the drag? What is the thickness of the boundary layer, and what is the effect on the drag of surface roughness, waviness, and protuberances? Before we can answer any of the questions, we must reduce the random fluctuations to an ordered system, and either guess, or deduce from theoretical considerations, a law for this ordered system.

The particles comprising the turbulent flow possess both linear momentum and rotational momentum; without discussing at this stage which is the more important characteristic of turbulent motion, let us concentrate attention on the linear momentum of the particles. Let us consider a point in a Cartesian system

of co-ordinates where the mean components of velocity in the directions of the co-ordinate axes are $\bar{u}$, $\bar{v}$, and $\bar{w}$. The velocity at any point is, however, by no means constant, but fluctuating continuously, though in no regular manner. Let us denote the fluctuating velocity components, *i.e.*, the amount by which the instantaneous velocity components exceed the mean, by u', v' and w'; then $u = \bar{u} + u'$, etc. We see then that the mean values of u', v' and w' are zero.

But not necessarily so the mean values of the squares and products of the velocity fluctuations. The mean values of the squares represent an interchange of momentum across a surface in the fluid and normal to this surface; and the mean values of the products, an interchange of momentum across a parallel surface. This interchange of momentum is equivalent to an internal stress in the turbulent flow, hence in general the fluctuating motion gives rise to six " apparent " stresses, three direct and three shear. If we concentrate attention on a thin boundary layer of a two-dimensional mean flow parallel to the x-axis, then the only " apparent " stress we need consider is the shear stress parallel to the x-axis, and this is equal to $-\rho\overline{u'v'}$. The shear stress due to the mean relative motion of adjacent layers of fluid is then $\mu\, d\bar{u}/dy$, and as the total interval shear stress in the fluid is equal to $\tau_{xy} = -\rho\overline{u'v'} + \mu\, d\bar{u}/dy$.

The Laminar Sub-layer

One would expect, in the immediate vicinity of the wall, that the fluctuating motion be restrained, and observation has shown this to be so. Von Kármán assumed a thin " laminar sub-layer " to exist, across which a very steep velocity gradient produces the high wall stress (*i.e.*, drag per unit area) characteristic of turbulent boundary layers. The laminar sub-layer is one of uniform shear, *i.e.*, constant velocity gradient. This is not surprising, since theory indicates that this type of laminar flow is always stable against any disturbance. Inside the sub-layer the term $-\rho\overline{u'v'}$ in the shear stress is of course of no importance; whereas in the region of fluctuating flow the viscous term may be neglected. The requirement of our theory is therefore to connect the two regions of flow.

2. *(a) Prandtl: Mixing Length*

The problem as stated by Reynolds has in recent times been developed by Prandtl and von Kármán, and results have been obtained which agree with experiment over a very large range of Reynolds number. Let us confine our attention to a mean flow in the x direction, and let us consider a particle situated in a layer where the local mean velocity is less than the instantaneous velocity of the particle. Let us suppose that the particle moves at right angles to the mean direction of motion a distance l, till it reaches a layer where the mean velocity is equal to the instantaneous velocity of the particle. If the particle now mixes with the surrounding fluid, without loss of momentum in the x direction, we see that the mixing length l is a length characteristic of the momentum interchange, and that further u' is equal to $l \times d\bar{u}/dy$. If we consider our shear stress to be produced by a pressure gradient in the x direction, the momentum transport theory gives us

$$\partial p/\partial x = -\rho\, d/dy\, (\overline{lv'}\, d\bar{u}/dy).$$

(b) Von Kármán: Similarity Hypothesis

Here we have to make another tentative guess to reduce our formula further. Von Kármán assumed that the mechanism of mixing was independent of viscosity and was everywhere similar; and that the mixing process at different points differed only in the scales of length and time. This assumption reduces the apparent shear stress to $l^2\,(d\bar{u}/dy)^2$, and further, on substitution in the equations of motion, gives us an approximation for $l = \kappa \,|\, (d\bar{u}/dy)/(d^2\bar{u}/dy^2) \,|$ where κ

is a universal constant. We now have an equation connecting the apparent shear stress in the turbulent region with the velocity distribution. If the similarity hypothesis is true, we may now solve with the help of dimensional analysis the problems of the turbulent flow in a smooth circular pipe, and the turbulent skin friction of a flat plate in a uniform stream.

Résumé of the Prandtl-Kármán Theory

Before we do so, let us survey our position. We have obtained a formal restatement of our problem, that the internal shear stress in the fluid is equal to $l^2 (d\bar{u}/dy)^2$; the similarity hypothesis gives us a measure for the mixing length l. We have neglected the effect of pressure variations on the mixing process, and assumed that, in a two-dimensional mean flow, the fluctuating velocities are also two-dimensional. Observation has shown that though this may be true for a wake, this cannot apply to a boundary layer.

Even if the mean flow over a boundary is two-dimensional, yet there are very large velocity fluctuations normal to the plane of flow. The Prandtl mechanism ignores both these effects, and Professor Taylor has shown that the momentum transport mechanism is untrue, since transverse pressure gradients must exist.

(c) G. I. Taylor: Vorticity Interchange Theory

We may assume alternatively that the mechanism of a turbulent flow is that of a vorticity interchange. Using the concept of mixing length as the characteristic length of the exchange mechanism, Professor Taylor has obtained formulæ which represent respectively a two-dimensional mean flow over a boundary where the vorticity is three-dimensional, and a wake where the mean flow is two-dimensional and the vorticity is also two-dimensional, *i.e.*, the axis of rotation of the fluid particles is normal to the plane of flow. In the first case, he obtains $\partial p/\partial x = -\rho\, \partial/\partial y\, (\overline{lv'}\, d\bar{u}/dy)$, which agrees exactly with Prandtl's formula. In the second case, Taylor obtains the formal reduction $\partial p/\partial x = -\rho l v'\, d^2u/dy^2$. Let us see how we can check these proposed formulæ.

3. Checks: Heat Radiation

The mechanism of transference of heat from a body in a fluid stream of small viscosity is similar to the mechanism of the transference of momentum. The formula for the distribution of temperature in the boundary layer or wake involves the term $l\overline{v'}$ in a similar manner to the Prandtl-Taylor formula for the turbulent boundary layer. Prandtl and Taylor agree that the distribution of temperature in the boundary layer of a heated body should be the same as the distribution of velocity. Prandtl's formula states that this is true also for the wake of a heated body, whereas Taylor suggests that in this case the temperature and velocity distributions are different. Experiments agree with Taylor's predictions in both cases, so it might be said that this constitutes a justification of the vorticity transfer theory.

The mixing process is probably a combination of momentum transport and vorticity transport. If an element rotating about an axis suffers a displacement normal to this axis, it exerts, so to speak, a " lift " force at right angles to its axis and the direction of displacement. There is thus a connection between the velocity fluctuations and the pressure gradient through the turbulent flow. If these effects be included in the momentum transport theory, the results will probably agree with those of the vorticity transport theory.

The position at present is very uncertain, due to the fact that the physical significance of the mathematical manipulations is not very clear.

4. Correlation

There exists an independent check on von Kármán's similarity principle. We can follow the fluctuating paths of particles in a turbulent stream and obtain the components of the velocity fluctuations. Now if for any given value of u' the corresponding statistical mean value of v' is zero, then the distribution of

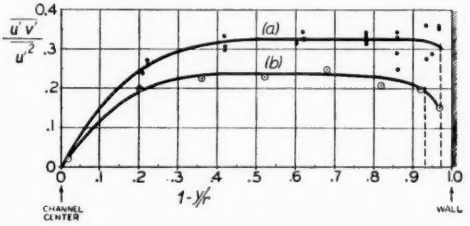


FIG. 5.

Correlation between turbulent velocity fluctuations, (a) Wattendorf (C.I.T.), (b) Reichardt (Göttingen).

velocity fluctuations will be perfectly random and there will be no apparent stresses or momentum transfer. If, however, with a value of u' we *can* associate a positive or negative statistical mean value of v', then we see that a transfer of momentum must take place, and that a correlation then exists between the turbulent velocity fluctuations. The magnitude of this correlation can be measured by a "correlation coefficient," which is a function of the turbulent velocity fluctuations, *e.g.*, $\overline{u'v'}/\overline{u'^2}$. Experiments in a rectangular channel of high aspect ratio show that this coefficient is reasonably constant over the main portion of the cross-section. This indicates constant correlation or similarity of the turbulence mechanism, as predicted by von Kármán, for the flow in a parallel channel.

It is reasonable to assume that this is true also for a round pipe, at least in the immediate vicinity of the wall.

5. Turbulent Flow in Round Pipes and over Smooth Plates

(a) Velocity Distribution

Now that the similarity principle has been checked for the flow in a turbulent boundary layer, we are in a position to apply dimensional analysis and the rule for mixing length. Except in the immediate vicinity of the walls, the mean velocity distribution of the turbulent flow in a pipe must be independent of viscosity, and so we expect that it would depend only on the shear stress at the wall, *i.e.*, the drag per unit area, τ_0 and the density. The square root of the ratio of these quantities, $\sqrt{(\tau_0/\rho)}$, has the dimensions of a velocity, and is called the "friction velocity." If we call the difference between the local mean velocity and the velocity at the centre of the pipe the "velocity defect," then by dimensional considerations, we expect the ratio of velocity defect to friction velocity to be a universal function of the relative distance from the centre of the pipe. We would expect that this relation automatically includes smooth and rough walls, if the magnitude of the roughness does not upset the main flow; experiment shows that our reasoning is correct (Fig. 6).

(b) Resistance Law

Now let us consider the flow near the wall of a smooth pipe. The only quantities which affect the velocity distribution are the shear stress at the wall,

the viscosity and density of the fluid, and the distance from the wall. We can obtain a non-dimensional measure of the velocity in this region by dividing the velocities by the friction velocity $\sqrt{(\tau_0/\rho)}$. Further, we can construct a kind of Reynolds number, using for length the distance from the wall and for velocity the friction velocity. Then the non-dimensional velocity must be a universal function of this friction distance parameter, or $u^* = u/\sqrt{(\tau_0/\rho)} = g\,(\rho\sqrt{(\tau_0/\rho)}\,y/\mu)$

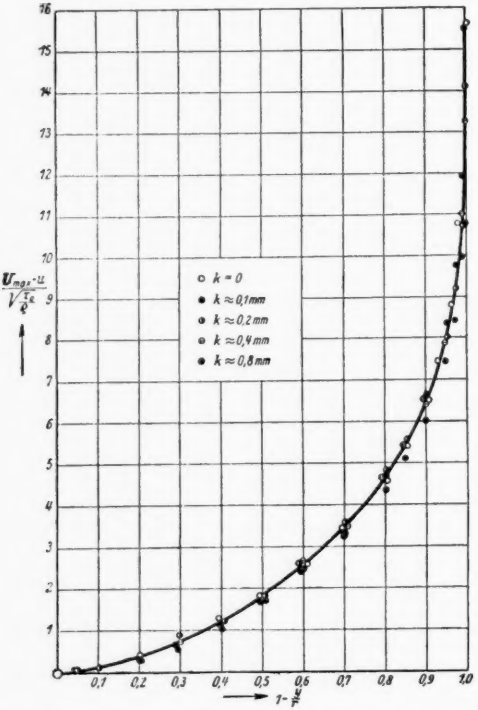


FIG. 6.

Universal velocity distribution in a round pipe.

$= g\,(y^*)$. We now apply the similarity principle to the flow just outside the laminar region. The rule for mixing length gives us a differential equation for u^*, and the solution shows that the non-dimensional velocity is a linear function of the logarithm of the friction distance parameter. Experimental results for a smooth pipe agree with this conclusion and give us the numerical constants required, and also the limit of the laminar sub-layer.

We may now combine the results for the flow near the wall with our previous general conclusions for the main flow. We can thus connect the resistance of the wall with the maximum velocity at the centre of the pipe, and hence we obtain, by an almost purely theoretical chain of reasoning, a law connecting the resistance coefficient of the pipe with the Reynolds number of the flow,

$$\sqrt{(2/c_f)} = 1/\kappa \log (R\sqrt{c_f}) + \text{const.}$$

This formula appears to hold over a very long range of Reynolds number.

(c) Smooth Plates

By a similar argument, a general law for the turbulent skin friction drag of smooth plates has been obtained; $\sqrt{(2/c_f)} = 1/\kappa \log (Rc_f) + \text{const.}$ This law appears to be exact over a very wide range of R.N., but is in a very inconvenient form. Fortunately, for high R.N., the law connecting $\log c_f$ with $\log R$ is practically linear, and this law is the basis of calculation of the drag coefficients of airships and fuselages.

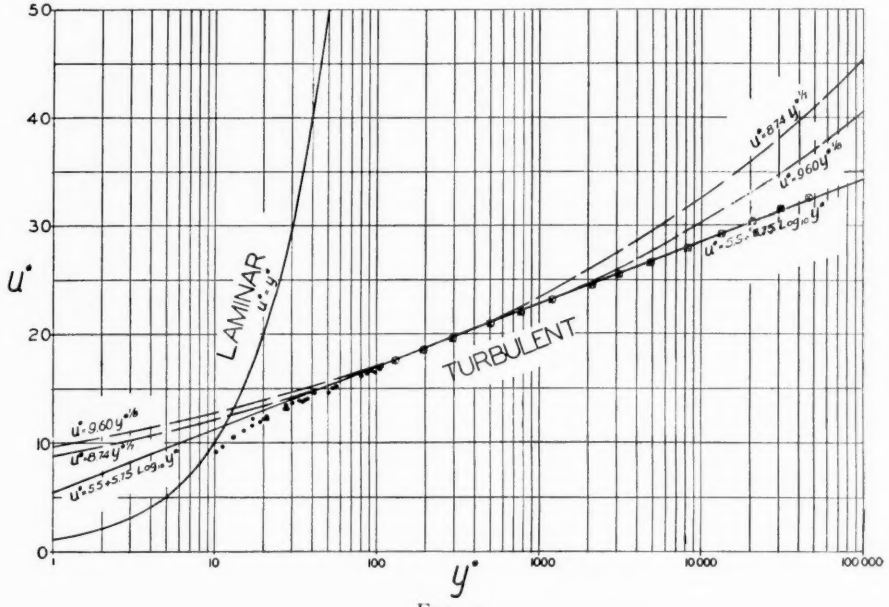


FIG. 7.

Universal velocity distribution near a smooth wall.

6. The Effect of Roughness

A surface is hydrodynamically rough when the height of the surface excrescences is of the same order as the thickness of the laminar sub-layer. Below a certain magnitude, their effect on the laminar sub-layer is very slight, and the surface may be regarded as hydrodynamically smooth; beyond this region, the drag is due both to skin friction and to normal pressure on the roughness elements. If the magnitude of the roughness compared to the sub-layer is very great, the sub-layer cannot exist, and the drag is then due to normal pressure only; it is therefore proportional to the square of the speed, *i.e.*, the resistance coefficient is constant.

If we consider a long plate in a parallel stream, then the sub-layer is very thin near the leading edge and thickens as we proceed downstream, hence the effect of roughness becomes less important; beyond a certain point, the influence of roughness is small. We see therefore that though it would certainly pay to adopt flush riveting or spot welding at the front end of a fuselage, little might be gained by adopting the same procedure near the tail. To eliminate the effects of scale in a model test, we should make the magnitude of the roughness elements proportional to the relative thickness of the sub-layer. The relative

effects on drag of normal pressure and skin friction would then be in the same ratio on model and full-scale, *i.e.*, the roughnesses are then dynamically similar.

Some experimental work has been done on the flow through rough pipes. The variation of resistance coefficient with Reynolds number bears out these general conclusions (Fig. 8).

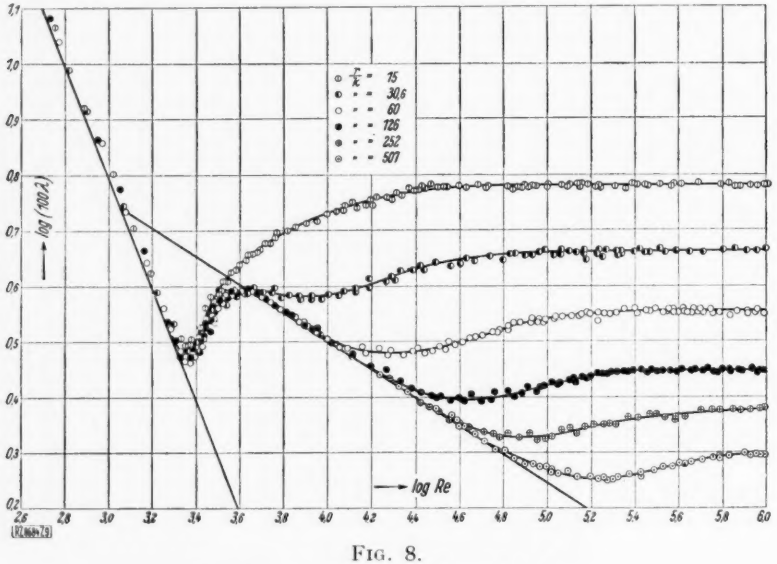


FIG. 8.

Resistance coefficients of rough pipes.

7. *Accelerated, Retarded and Curvilinear Flows*

We are interested primarily in the behaviour of wings, and it would assist our theoretical attack on stalling and minimum drag if we understood fully the effect of pressure gradient and curvature on a turbulent boundary layer.

As far as accelerated or retarded flows are concerned, since there is a pressure gradient along as well as across the boundary layer, it seems that to represent the exchange mechanism *two* mixing lengths are required. Dr. Goldstein has recently deduced a suitable formula, but it has not yet been applied to experimental results. No satisfactory theory has yet been made to fit observations of flows with pressure gradient.

Let us now consider the flow in a curved channel. At the outer wall, *i.e.*, the concave boundary layer, the slower moving particles nearer the wall are acted upon by a smaller centrifugal force than the faster particles farther from the wall; this instability causes an increase in the thickness of the turbulent portion of the boundary layer on the other hand, the stable arrangement of centrifugal forces at the convex boundary layer causes a *decrease* in the extent of the turbulence; in neither case is the laminar sub-layer affected. The thickness of the *concave* boundary layer is very sensitive to curvature. The curved boundary layer, again, has not yet had an exact mathematical treatment.

8. *The Turbulent Boundary Layer: Résumé*

This presentation has attempted to link up the mechanisms suggested by Prandtl, von Kármán, and Taylor, for the turbulent boundary layer. The actual

flow is probably very complex, and the applications of these mechanisms, even to such simple cases as the turbulent flows between parallel plates and in round pipes, are not free from inconsistencies; these inconsistencies have not been mentioned, in order not to complicate the argument unduly. Nevertheless, the logarithmic laws obtained appear to hold over a very long range of Reynolds number, and, though their derivation may be open to criticism, the laws are probably nearly correct.

The distribution of the components of the velocity fluctuation at any given point appears to follow the " random error law," and so from a statistical basis it is possible to make an attack on the nature of turbulence.

Our experimental knowledge of the structure of turbulent flow, together with the logarithmic laws of turbulent skin friction, may be used to explain many phenomena of interest to aircraft engineers.

Part IV.—Applications of Boundary Layer Theory

1. Streamline Bodies: Airships

Nobody nowadays wants to build an airship; but since the airship shape is a simplified form of aeroplane fuselage, and since a very large amount of work has been done on airship models, the results obtained may be applied, with certain reservations, to fuselages. We are interested in, first, the scale effect, for the extrapolation of wind tunnel results to estimate full-scale drag; secondly, the effect of shape on drag; and thirdly, the possibility of calculating the drag without the necessity for model tests. Let us first examine the knowledge gained from the study of airships.

Early Anomalies

In the usual region of experimental Reynolds number, the transition point between the laminar and turbulent flow, and hence the drag coefficient, is very

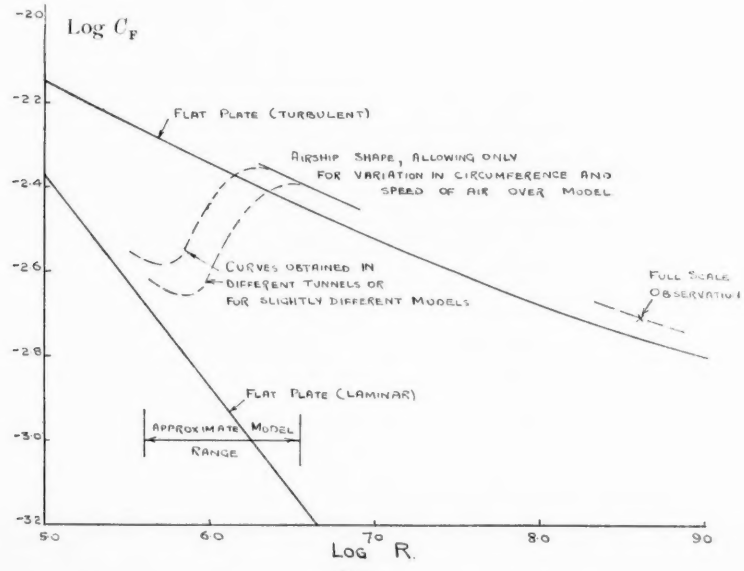


FIG. 9.

Skin friction of flat plates and streamline bodies of revolution.

sensitive to changes of R.N. and turbulence of the airstream. Hence different tunnels give quite different drags for the same model at the same R.N., and slightly different models in the same tunnel at the same scale may have widely differing drag coefficients. The effect of increase in the turbulence of the airstream or of increase in R.N. is to move the transition point forward, and in the full scale, this point is very near the nose. If, therefore, we increase artificially the amount of turbulence in a wind tunnel, we can obtain exactly the same flow pattern as on the full scale, and the drag coefficient must now have some connection with the full-scale value. We now find that the effect of shape on drag is quite small for the same fineness ratio.

Estimation of Drag

The pressure, or form, drag is very small; the bulk of the drag is therefore due to turbulent skin friction. The only theoretical basis we have is the exact flat plate law, which, in the region between the model range and the full scale, gives a nearly linear connection between $\log \kappa_F$ and $\log R$. We may take as a rough rule, that the skin friction drag of a streamline shape is the same as that of a flat plate of equal area at the same R.N.; we will not be far out. If we take into account the variation in circumference and increase of velocity over the surface of the model, then calculation agrees almost entirely with model tests. We can say that if the fineness ratio is over, say, 5:1, then the net effect of double curvature and pressure gradient on the turbulence law is small. These approximate rules appear to hold up to full-scale Reynolds number.

Application to the Design of Fuselages

Actual fairing lines are probably unimportant. For the same fineness ratio, the skin friction drag is sensibly constant, and so, from the structural, spinning, and form drag points of view, a blunt tail is to be preferred. The centre portion of the fuselage should be nearly cylindrical. For smooth fuselages, the flat plate law may be used to obtain an estimate of drag.

2. *Aerofoils*

Aircraft design requires certain aerofoil data, which must either be calculable theoretically or determinable from tests on airfoils in wind tunnels. These are maximum lift, drag, slope of lift curve, angle of no lift, and moment coefficient. These latter two are properties which are practically independent of the viscous forces acting on the aerofoil, and may accordingly be calculated quite easily and accurately by inviscid fluid theory. The first three items are dependent on the action of the viscous forces; if it is not possible to calculate them, we must have some information as to the effect of scale and wind tunnel turbulence on experimental results, so that these may be interpreted correctly.

(a) The Stalling of Aerofoils

There are three physical processes involved in the phenomenon of stalling:—

i. *Front Separation.*

It has been shown that a laminar boundary layer has small powers of resistance against an adverse pressure gradient. Except at the smallest incidences, the point of maximum suction is very near the leading edge. Beyond this point the pressure increases again, and calculations of the theoretical pressure distribution show that this increase is very rapid for thin aerofoils, and fairly large for thick ones; hence, if transition to turbulent flow has not occurred in the boundary layer before a very short distance behind the maximum suction point, separation of the boundary layer from near the leading edge will occur. As would be expected, front separation results in a sudden and very great loss of lift and increase in drag.

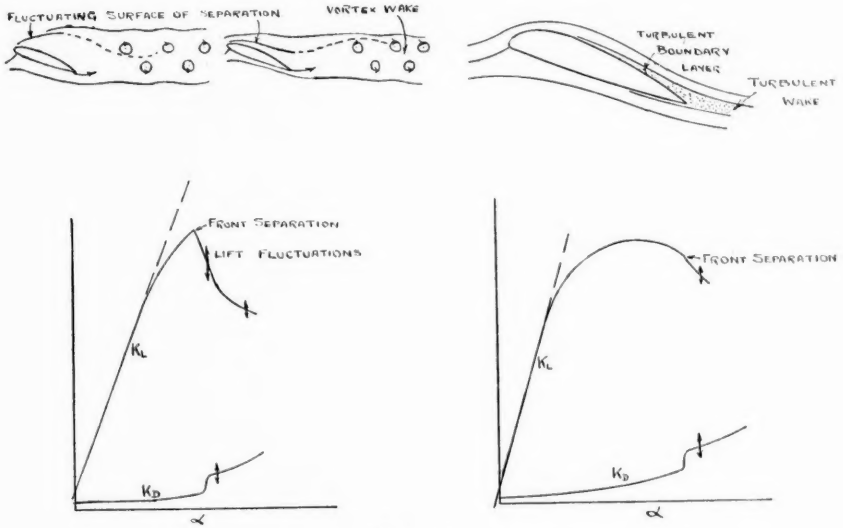


FIG. 10.
The stalling of aerofoils.

The separated stream flows clear of the aerofoil, leaving a nearly stationary "dead water region" between itself and the upper surface. The surface of separation is unstable, and assumes the form of a stationary wave. Over the aerofoil, the surface of separation is oscillating slowly though through a wide angle, causing the corresponding large and comparatively slow fluctuations in lift and drag.

ii. *Rear Separation.*

The adverse pressure gradient over the rear portion of the upper surface of an aerofoil causes an appreciable thickening of the turbulent boundary layer. The appreciable displacement of the main stream, together with the pressure drop through the turbulent boundary layer, cause the lift curve to depart from linearity at quite low incidences (about 5°). As the incidence is increased, the slope of the lift curve decreases continuously, and the drag rises smoothly.

iii. *Stagnation Point Turbulence.*

The arrangement of centrifugal forces in the boundary layer near the front stagnation point is unstable, since the faster particles farther from the surface of the aerofoil are acted upon by a greater centrifugal force than the slower moving particles nearer the surface. Dr. Piercy pointed out, in 1928, that this instability is likely to cause turbulence to arise at the front stagnation point. The main stream suffers a great acceleration between the stagnation point and the point of maximum suction, and for a thin aerofoil, this is very great indeed. We might expect, therefore, that if turbulence did appear at the leading edge of a thin aerofoil, it would be damped out in the subsequent acceleration; in the case of a thick aerofoil, we might expect the turbulent boundary layer to survive the smaller acceleration, and so to aggravate rear separation.

The behaviour of aerofoils near the stall is very complex, since normally all three processes are working simultaneously, and tend to mask and modify each other. In general, aerofoils fall into three groups, according to the predominating

influence at work. With thick aerofoils, front separation, and hence the onset of lift and drag fluctuations, are usually delayed to past the point where maximum lift occurs. In the case of *thin* aerofoils, front separation occurs before the lift curve has departed very much from linearity. The third group is that in which stagnation point turbulence plays an important part in causing the stall to be definitely due to rear separation only; front separation probably occurs at high incidences.

(b) Scale Effect

The three processes upon which the lift of an aerofoil depends are affected by scale and wind tunnel turbulence; it is therefore of importance to study the effects of scale and turbulence on lift in order to correlate wind tunnel observations with the full scale. Tests may be carried out in a compressed air tunnel and in an atmospheric tunnel with varying degrees of turbulence. Boundary layer observations may be impracticable or tedious, so it is usual to measure only the aerodynamic forces on the aerofoil, and to deduce its behaviour from the curves obtained.

Since Reynolds number represents the ratio of inertia to viscous forces, we would expect at higher Reynolds number the effects of viscosity to diminish, *i.e.*, the tendency for front and rear separation to occur to be reduced, and a higher maximum lift coefficient to be obtained. We would similarly expect the instability of the centrifugal forces in the boundary layer near the stagnation point to decrease with increase in Reynolds number.

Compressed-Air Tunnel: Effect of Variations in R.N.

Representative aerofoils of 6 : 1 aspect ratio have been tested in the C.A.T. (R. & M. 1627). The data provides information as to the behaviour of a wing at different Reynolds number.

R.A.F.28 Aerofoil (Fig. 11)

Front separation is the predominating effect for this thin aerofoil; as expected, k_{Lmax} increases with R.

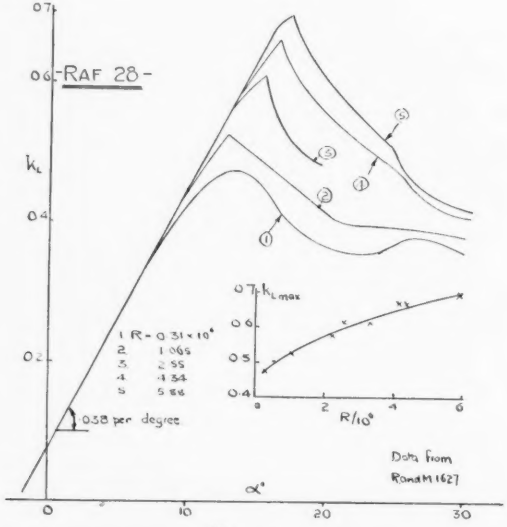


FIG. 11.
Scale effect on lift, R.A.F. 28 aerofoil.

R.A.F.48 Aerofoil (Fig. 12)

Front separation appears to take place at an incidence greater than that corresponding to maximum lift; the gradual reduction of the slope of the lift curve indicates that rear separation is the predominating effect. k_{Lmax} in this case also increases with R.

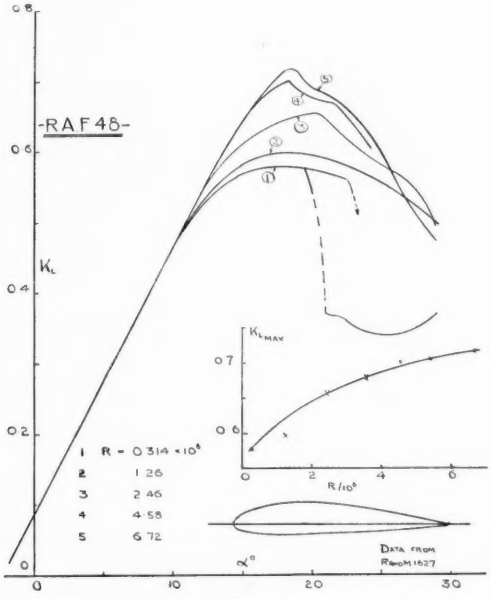


FIG. 12.

Scale effect on lift, R.A.F. 48 aerofoil.

Göttingen 387 Aerofoil (Fig. 13)

Stagnation point turbulence at low Reynolds number prevents a stall due to front separation; abnormally high values of k_{Lmax} are therefore obtained. k_{Lmax} decreases with increasing R, apparently due to decrease of turbulence effect, till about $R = 4 \times 10^6$, where this effect seems to disappear. For greater values of R, front separation then occurs in the usual way, and k_{Lmax} now *rises* with R. At about $R = 4 \times 10^6$, it seems that both types of stall are possible.

There does not seem to be any great difference at high Reynolds number between these aerofoils as far as maximum lift coefficient is concerned; this shows the danger of a literal interpretation of small-scale wind tunnel results.

Effect of Turbulence Variations

In the case of a thin aerofoil which undergoes front separation, the boundary layer is laminar over the front portion. Increase of wind tunnel turbulence, as in the case of the airship shape, causes forward movement of the transition point resulting in a delay of separation. Increase of turbulence therefore has the same effect as increase of Reynolds number on maximum lift coefficient. If we assume that the flow pattern is determined by the maximum lift coefficient, then we may obtain by suitable variations in tunnel turbulence the same flow pattern in a wind tunnel as on full scale; one flight test would be sufficient for calibration.

Scale Effect on Drag

Not much agreement has been obtained between full-scale and model minimum drag coefficients, since drag is very sensitive to surface texture and inaccuracies of profile. Both similarity of flow pattern and dynamical similarity of surface texture are required. The former may be obtained by suitable adjustment of turbulence; the latter depends on the effects of roughness on drag, which are not very well understood.

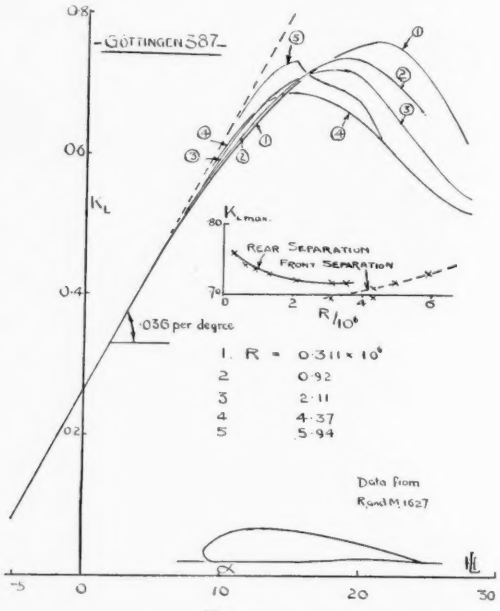


FIG. 13.

Scale effect on lift, Göttingen 387 airfoil.

The Time Effect on Lift

One dimension which has not entered explicitly in this presentation is that of time. It is well known that when the angle of incidence of a thin wing is increasing rapidly, the lift coefficient attains a much higher value than in a steady glide. This effect is of importance in connection with landing, and with the stressing of wings for the gust case. We remember that front separation is due to accumulation of a retarded boundary layer. If we examine the initial motion of a circular cylinder, we find that it traverses an appreciable distance before the retarded boundary layer accumulates sufficiently to cause separation. If, therefore, the incidence of a thin wing is increasing rapidly, the front separation effect is temporarily hidden. Rear separation takes place when the lift coefficient is rising from about 0.5 to the order of unity. At about this instant, depending on the rate of increase of incidence, sudden separation takes place. There is consequently a very great drop in lift. This might lead in practice to a heavy landing, perhaps with one wing down; this effect therefore needs much further investigation. It can be seen, therefore, that boundary layer study is of importance, not only in connection with the " economics " of flight, but also in connection with questions of stability and strength.

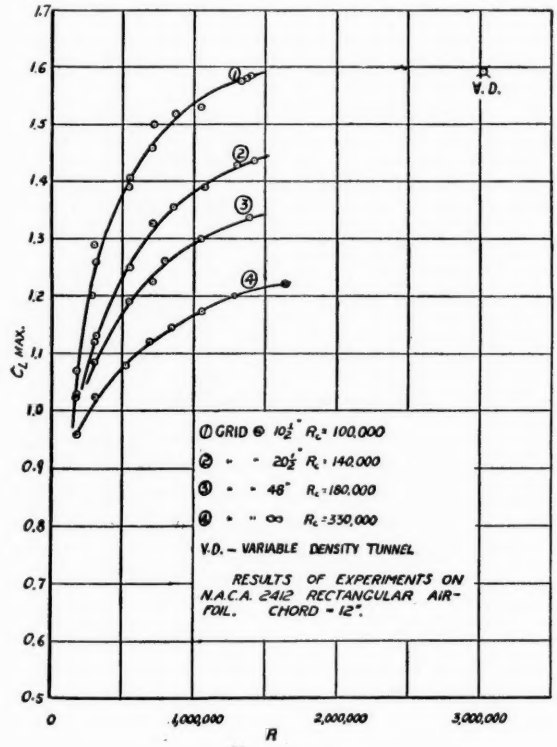


FIG. 14.

Effect of different degrees of turbulence on maximum lift coefficient (N.A.C.A. 2412 airfoil).

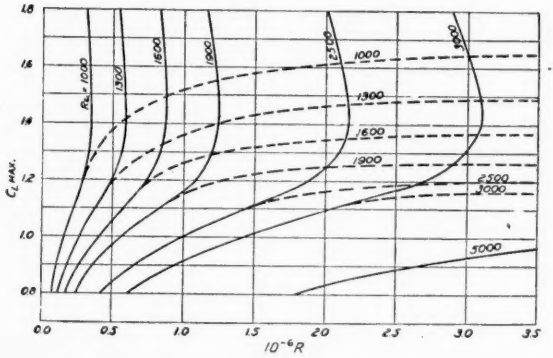


FIG. 15.

Theoretical curves for maximum lift coefficient as a function of R and external turbulence (dotted portions conjectural).

The Theoretical Calculation of Aerofoil Characteristics

It would greatly increase our understanding of the behaviour of aerofoils if we could calculate from a theoretical basis their characteristics. Von Kármán is attacking the problem of laminar separation. After developing a special method applicable to wing profiles for calculating the separation point, von Kármán obtains a relationship between k_{Lmax} and R for different degrees of external turbulence. Up to about $k_{\mathrm{Lmax}}=0.6$, the curves agree in shape with the experimentally determined curves (see Figs. 14 and 15).

A thick symmetrical aerofoil has been approximated to by an elliptic cylinder. The theoretical lift curve obtained agrees in general shape with those such as for Göttingen 387.

Conclusion

The trend of modern high-speed aircraft design is towards the clean, high-speed aircraft. To reduce profile drag and increase disposable load, it is necessary to reduce wing area to a minimum. The designer must know what maximum lift coefficient he is to expect from his wing section, and he must therefore know how to interpret the results of his wind tunnel tests. The margin between profitable and unprofitable operation of a commercial machine is nowadays so small, that the designer must apply the conclusions of boundary layer theory to reduce the skin friction and hence operating costs to a minimum. The day is therefore probably not very far distant when the designer's technical equipment will include at least the fundamentals of boundary layer theory.

The 595th Lecture delivered before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS

The Royal Aeronautical Society held the first meeting of its 1935-36 Session in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, on Monday, October 21st, 1935, the President (Lieut.-Colonel J. C. T. Moore-Brabazon) in the chair.

A paper, entitled " Piloting Commercial Aircraft," by Major H. G. Brackley, D.S.O., D.S.C., F.R.G.S., was presented.

The PRESIDENT: The Society was privileged to be able to commence its autumn session with a paper by Major Brackley, who had filled the post of Air Superintendent of Imperial Airways, Ltd., since 1924, so that he had a very catholic knowledge of the subject of piloting commercial aircraft. Needless to say, he had served during the war; he was an entrant for the Atlantic flight in 1919, was Chief Pilot to the Handley Page Transport Company in 1920 and 1921, had been a member of a British mission to Japan in the years 1921-23, and had acted as Advisor to the Japanese Naval Air Service. He held many decorations, which were well deserved.

It was right that the Society should commence its Session by discussing the piloting of commercial aircraft, a subject which became more and more important as time passed.

PILOTING COMMERCIAL AIRCRAFT

BY

Major H. G. BRACKLEY, D.S.O., D.S.C.

(Air Superintendent, Imperial Airways)

This is the first time I have been given the honour of reading a paper before the Royal Aeronautical Society, and I propose to give you a brief review of the progress made in commercial air pilotage and some of the problems the present-day captain of aircraft has to tackle on every day all-the-year-round flying in Europe and on the Empire routes to Africa, India and Australia.

It is perhaps desirable at the outset to see how commercial flying differs from military and private flying.

In the first place commercial routes are fixed and aircraft operate to schedule with many ground aids, compared with R.A.F. operations which of necessity have to be carried out without the assistance available on regular organised routes.

In commercial flying, formation and any flying involving steep turns and sudden manœuvres must be avoided. Passengers' comfort must be studied. Flights are of longer duration, and the commercial pilot flies many more hours during the year than does a military pilot.

Night commercial flying differs from night bombing raids. The commercial aircraft carries its load of passengers, mails and freight, on an organised route and lands with its heavy load on an aerodrome properly organised to receive it; whereas the bomber has to fly without ground aids to dispose of its load and returns " light " to land, possibly on an unlighted aerodrome.

Most commercial pilots would, no doubt, find it difficult to fly the modern fighter, and the fighter pilot would not be able to fly our services. So that—in short—military and commercial flying tend to diverge.

The extraneous subjects involved in this paper are numerous and I have not attempted to go into detail.

Papers on fog landing devices and ice formation problems have been read before the Society, so there is no need for me to dilate on these subjects.

As in most other walks of life, science is well to the fore in aviation with the production of many new instruments and apparatus, which have been responsible for raising the technique of flying and making it safe and reliable. In the last few years we have seen night flying established, and flying and landing in nil or very low visibility become almost a regular feature of commercial aviation.

Most of the improvements have been due directly to more reliable engines and aircraft and to the greater reliability and accuracy of aircraft wireless and direction finding as well as to instruments which enable the pilot to fly by them for hours on end without becoming fatigued.

With the development of still more instrumental aids to navigation, our greatest enemy, fog, will put less difficulty than at present in the way of commercial aviation.

Brief History

Whatever may be written or said in future years as to the history of British civil aviation, a great tribute must always be paid to those veteran pilots who in the earlier years of civil aviation had few of the many extraneous aids to air navigation such as are available to present-day commercial pilots.

Such men as F. L. Barnard, Foot, Hinchcliffe, Minchin and Powell set a very high standard of pilotage and a very fine example to the future air liner commander. Their untimely deaths, occurring when not engaged in their normal air liner duties, robbed British civil aviation of some of its best pilots at a time when their services were badly needed.

To those of the original band of pre-war and war pilots who are still actively engaged in regular air line work, and whose skill is greater than ever, and whose hours at the controls exceed ten thousand, much credit must be given for the part they are playing in enhancing the tradition and increasing the prestige of British aviation. Their vast experience is invaluable in teaching our future commanders and in the development of Empire airways.

When commercial flying began in 1919 with a heterogeneous collection of war machines we had two pioneer companies, the Airco and Handley Page Transport. The Airco Company used the De Havilland 4, 9 and later the 16 types, whilst the Handley Page Company used mostly modified twin-engine bombers. The organisation was very sketchy; engines were difficult to start, and it was not unusual for the complete load to be transferred to another aircraft for this reason. There was no weighing of passengers or luggage. Weather reports and forecasts were unreliable and upper wind reports were almost non-existent. The wireless service was limited to terminal aerodromes and aircraft sets could never be depended upon. Direction finding was not even practised. Aircraft instruments were most elementary and the old style compasses were most unsuitable for flying in anything but good weather.

The result was that the flying technique was quite different from that of the present day. For instance, in conditions of low cloud and poor visibility, the pilot had to fly low to avoid losing himself. This in itself was highly dangerous, and no pilot who is still engaged in commercial aviation can look back on those days without feeling he was lucky enough not to hit anything. But to fly in cloud for lengthy periods, except when the weather was known to be clear ahead, was far more dangerous, because the pilot would get off his course through not knowing the upper winds and not having assistance of wireless, and when

coming down again through the clouds, he was fortunate to see the ground without hitting it!

Development

From the outset, air transport companies strove to improve their aircraft and engines, but had a difficult task in view of the financial stringency of those pioneer days. It was not until 1924 when Imperial Airways was created, comprising a combination of the four companies then operating, that real development began. From that time improvement made itself felt in every department. The single-engined aircraft, which had done magnificent pioneer work, gave way almost entirely to the multi-engined type, which provided a higher margin of safety and immunity from forced landings outside recognised aerodromes.

Comfort for passengers and better aids to navigation were produced and more reliable instruments were evolved. Open cockpits gave way to enclosed control cabins, and this led to the adoption of uniforms for the captain and crew and started the dignity of a new tradition. Up to this time the pilot's seniority and skill used to be judged by the amount of grease on his Sidcot suit and flying helmet!

Those of us who had been so accustomed to the fresh air of the open cockpit were loath to give it up, for the feeling of claustrophobia was repugnant to us. Needless to add, we were soon converted.

From this time commercial aviation took on a new aspect. Imperial Airways were the first to start the first officer grade—the first officer being a qualified pilot with engineering and later with wireless and navigating qualifications.

Discipline in the control cabin, modelled on marine lines, became a recognised practice, and to-day the control cabin is regarded in the same way as the bridge of a ship. It is the rule in our company that none but the crew and others in possession of a special pass are permitted to enter the control cabin.

Weather reports, forecasts and upper wind data have been scientifically improved and their compilation and dissemination have become better organised.

Similarly, in the wireless field, aircraft telephony and telegraphy sets have been improved and important and far-reaching developments in direction finding have been tried out and put into practice.

All these things make for greater reliability of operation and allow the pilot to give more attention to navigating in worse weather conditions than was possible in the earlier days. The result is that to-day we are able to operate scheduled services with a regularity percentage of over 95.

Aircraft and Crews

Present-day commercial aircraft are practically all multi-engined. In the case of Imperial Airways' Empire fleet they are all of the four-engined type, luxuriously equipped, carrying big loads of passengers, mail and freight, with a crew of four as far as Karachi and Kisumu, and a crew of two on the small four-engined types operating between Karachi and Australia, Kisumu and Cape Town.

The captain of one of these aircraft, instead of operating his wireless himself, has his own operator, who on certain of the European and the Empire routes combines this important work with the duties of first officer or relief pilot.

The chief duties of a captain are to fly his aircraft safely and with absolute reliability, and to give his passengers the maximum degree of comfort consistent with existing weather conditions.

To-day, however, the captain is, in addition, looked upon more and more as a host to his passengers on the Empire routes. He sees to their comfort and well being. It is a fact that the passengers themselves look upon the aircraft captain as they do the captain of a ship.

The consideration of the above aspects of a captain's duty leads to the subjects of :—

(*a*) Controllability of aircraft.
(*b*) Control cabin comfort and instrument board layout.

I propose here to go over briefly the various points which under these headings need to be watched.

Controllability of Aircraft

The main essential is to have an aircraft which is stable on its three axes, and does not need constant trimming to keep it at the required cruising attitude. It should be fully controllable throughout its entire speed range, and it should not be " heavy " or ineffective on any one of its controls.

The pilot is saved considerable fatigue if his controls are nicely balanced and do not require " paddling " on the rudder or constant correction on one of the controls to keep the aircraft on its course.

Control Cabin Comfort and Instrument Board Layout

The pilots' seats should be comfortable and adjustable and the rudder pedals should be of sufficient area to give the maximum support to the feet.

A clear view forward, to the sides and downwards is essential. This is particularly important when taxying and flying in conditions of bad visibility.

When in a turn, it is important that the windscreen frame or other opaque portions of the control cabin or wing do not obstruct the pilot's view.

Windscreen wipers, in general, have not been very successful, but it is important to find a type which will work and keep on working at all normal speeds and under all atmospheric conditions. The alternative is to provide some other means of keeping the windscreen clear.

Where sliding side panels are provided, it is important that these should be at such an angle that the crew are not blown out of their seats or swamped with rain water when the panel is opened. Too much stress cannot be laid on the necessity of making the control cabin watertight.

It so often happens that the control column layout makes it difficult for either pilot to see the navigating instruments without altering his attitude. This is a handicap when flying solely by instruments for prolonged periods.

The comfort of those occupying the control cabin is of much more importance than is perhaps generally realised. If a pilot feels half frozen, obviously he is at a disadvantage, maybe sufficiently so to affect his efficiency, for instance, when negotiating a difficult fog or night landing. I should like to see all control cabins of the future heated as are the best passenger cabins to-day.

So much has been written about instrument board layout that there is no need for me here to go into details. Instrument flying is to-day practised by practically every pilot. Confidence in the readings of the instrument panel has become an essential feature of flight training and technique. But to make the best use of these instruments, it is most important to have them grouped, as experience has shown, in such a way as to give the pilot an unrestricted view without having to constantly refocus the eyes.

For night flying indirect lighting, rheostat controlled, is considered essential.

Although present-day navigating instruments of British and foreign design are very reliable, air speed indicators still go out of action occasionally when flying in continuous heavy rain. Specially designed water trap in the pitot head has not as yet proved entirely successful. Duplicating the A.S.I. and pitot head does not always overcome the difficulty.

The automatic pilot will doubtless be a valuable asset when still larger aircraft are produced. Its present shortcomings are its cost, weight and the

necessity of designing the aircraft control layout specially to take the stresses it imposes, but its merits for long distance oversea flights on large aircraft might well outweigh its disadvantages. Much depends on the particular circumstances.

All-the-year-round flying in Europe is generally considered to be more difficult than on any of the present-day Empire routes. With the ever increasing air traffic, the captain's task is not made easier. But the authorities in all countries are fully alive to the risks of collision and have organised a " control area " around each airport of importance. Whilst we must at all costs avoid collision risk, we must also watch the methods of control lest these become too rigid and impossible of operation.

Pilotage in fog conditions calls for more skill and experience than any other form of navigation.

Most of our captains have learnt their fog and cloud flying by the aid of a turn and bank indicator, and Imperial Airways were the first to standardise this type of instrument on all their aircraft. It is only during the last two years that those excellent instruments, the artificial horizon and directional gyro, have been added to all our aircraft, and instrument flying has increased greatly in efficiency.

Before he can expect to fly by instruments, a pilot must be able to keep a straight course and hold the aircraft on an even keel on a clear day.

There are plenty of junior pilots who cannot keep their aircraft straight even when the ground is visible, simply because they cannot concentrate on their instruments. When they enter clouds they brace up rigidly into a state of nervous tension and the sooner they get out of the clouds and see an horizon the better. An experienced pilot when flying by instruments relaxes himself and his limbs react to the brain without throwing undue strain on his nervous system.

I do not know how many of the training schools in England teach instrument flying by other methods than " under the hood." I believe most schools teach their pupils solely with a turn and bank indicator generally in good weather conditions with an instructor in an open cockpit.

When " under the hood " the pupil has the knowledge that the instructor is with him and that the air conditions are reasonably smooth. If more instruction in actual clouds could be given the pupil would benefit considerably from the experience. The best method would appear to be, first to teach the pupil to concentrate on his instruments whilst " under the hood," and the second part of the training should be done in cloud where the pupil can put his knowledge into practice under the actual conditions.

When cloud flying one usually meets different air currents which are liable to upset the equilibrium of the aircraft more than when flying in clear weather.

Most air transport companies have experienced difficulty recently in obtaining pilots fully qualified in instrument flying. Pilots from schools or the Service have been taught to fly " under the hood " and apart from a few trips of short duration in cloud they have no other experience. Consequently, when a new pilot joins an air transport company he is very surprised at the actual weather conditions with which the more experienced pilots are able to cope.

Marine Aircraft

I will now pass on to the flying boat side and describe the method of piloting marine aircraft in the Mediterranean.

The formalities of departure are usually carried out while the engines are warming up at the mooring, but they are stopped while mail, freight, baggage and passengers are taken alongside. The operation of getting away from moorings in confined spaces is greatly facilitated by the use of a " tail release," so that the aircraft lying head to wind at the mooring has a rope from its tail tied taut to some convenient anchorage ashore or on another mooring.

The bow mooring is reduced to one single rope with a slip line rove through the eye on to the bollard of the aircraft.

As soon as the passengers are aboard, the steward, who assists them up the gangway, counts the passports and tickets, sees that all the many documents are aboard, closes the hatches and reports " all correct " to the captain. The engines have meanwhile been started and the captain signals by whistle to the wireless operator who acts as bowman to slip, whilst he himself operates the " tail release."

Most large marine aircraft take-off with the variable incidence wheel at a position very remote from the cruising and landing positions. The loads on the control wheel can be high whilst getting on to the " step " during take-off.

During flight, watches are kept one hour at the controls and one hour look-out by the captain and first officer.

It is usual to assume that the wind at sea will more approximate the wind given in the forecast for 2,000 feet than that for the surface.

" Fixes " can be obtained at sea often from ships in sight, though it is difficult sometimes to establish wireless communication.

The Aldis lamp can be used to establish the primary contact if the sun is in a suitable position by signalling " Jau," " You should man your radio room as I wish to communicate with you."

Cook's lists of sailings carried on board gives a clue to the ship's name.

Position " fixes " by two D./F. bearings from two ships in stated positions or two bearings from one ship with a time lapse have not proved as useful as might be expected, and at times no fix at all has been obtained after careful bearings have been given, due to unknown errors.

Alighting calls for no comment except in glassy calm conditions when it has been found that paper balls spread by a motor boat which itself disturbs the surface is a good practice.

We prefer to operate drogues from bow bollards. This gives better control than when operated from the aft hatch.

The aircraft is moored during refuelling halts by one 5-inch circumference rope over the bollard, unless it is blowing hard when two ropes are used.

In calm weather the refuelling barge which approaches from ahead of the aircraft drops down alongside the hull, picking up the main mooring as she comes. In rough weather she lays her own anchor ahead of the aircraft and drops down from that so that she can haul back out of danger if necessary. In heavy swells she does not even come alongside, but lies on her own anchor ahead of the aircraft so that no damage can be done.

Alighting at night is effected along a normal paraffin flare path of six floating flares. A landing light is used from the aircraft, but it is found on many nights an imperceptible mist arises from the water which destroys the usefulness of this light. A mist piercing light that does not throw the beam back to the pilot's eyes is a necessity.

The landing lamp is invaluable while taxying at night, and in harbour, when congestion of traffic makes it desirable, the aircraft is preceded by a motor launch which carries by special arrangement with the harbour authorities a light blue light. This colour was chosen as it is readily picked out from among the mass of red, green and white lights in the average harbour.

A control boat and a patrol boat are used when alighting at night on fast flowing rivers such as the Nile. Feluccas and other small craft floating down-stream, often under little control, need very careful watching.

Piloting commercial aircraft on the desert routes requires physical fitness and stamina. Long hours in the control cabin and flying over monotonous country during summer with the constant change from the comparative cool of the upper air to the furnace-like heat on the ground calls on the pilot's vigour reserve to a marked degree. Every provision should, therefore, be made for

this eventuality by taking plenty of open air exercise, consuming good wholesome food and enjoying moderate habits.

The success of any flight over the Empire routes lies in the hands of the captain of the aircraft.

It is difficult in some places to secure reliable meteorological information, so that consideration must be given to the weather obtaining on the day of the flight combined with a knowledge of the seasonable weather in that area.

In the southern half of the Continent of Africa, in particular, special consideration must be given to the aerodrome altitude, aerodrome dimensions and/or weather if difficulties are to be avoided. Aerodromes at 4,000 to 5,000 feet above sea level must be treated with respect. Hangars are few and far between, so that the safety of the aircraft away from its base is the captain's responsibility, and he must watch or be advised of any change in the weather which may affect his aircraft. Many a tedious night has been spent after a long tiring flying day taxying the aircraft head to wind during tropical storms, but unless this is done serious damage might occur, should a severe storm strike the aircraft when not head to wind. Our captains pay the greatest respect to the " haboobs " of the Sudan. If one is met en route it is advisable to circumnavigate it or attempt to get over the top of it.

Night flying is generally associated with calm conditions, and were it not for this asset captains would find it very difficult to operate over long distances over unlighted and uninhabited country where wireless aids are few.

A difficult section for regular night flying lies between Kisumu on Lake Victoria Nyanza and Juba in the Sudan. Violent storms may occur any evening throughout the year, making wireless communication unreliable. The section Juba to Atbara, north of Khartoum, also has the same difficulty during the rainy season.

Pilots would welcome aerial beacons every 100 miles. At present, these only exist at a few landing grounds. At most aerodromes floodlights are provided and the conventional paraffin flares arranged in the form of an " L " with the short arm facing the wind. On a fine clear night the flare path is visible for about 50 miles, but when bush fires are prevalent, the aerodrome flares are difficult to pick up because of smoke clouds which reduce visibility and produce a haze.

When attempting to reach an aerodrome in a sandstorm, particular care must be taken to sum up the probable visibility, both forward and vertical, that will occur at the time of arrival. The captain must judge this from the weather reports.

There are two safe methods of reaching a destination in poor visibility due to sand or dust. The first, by flying low over a known course and losing altitude to say 600 feet when the ground can usually be seen (provided there is a horizontal visibility of 200-300 yards) and by following tracts, rivers, etc., to the aerodrome. The second is to fly on a wireless bearing until over the aerodrome and then lose height until the landing ground can be seen. With this method, however, the visibility should not be less than 800 yards, because wireless communication during sandstorms is often unreliable, due to static interference. It is advisable not to continue or start on a flight when the visibility at the destination is less than 300 yards, although under these conditions the ground sometimes comes into view for landing from at least 600 feet. Whilst it is safe for an experienced captain to approach places like Baghdad and Basra under these conditions, relying on his local knowledge to effect the landing, it would not be prudent to adopt the same procedure with regard to landing grounds like Rutbah Wells, which have bad approaches. Familiarity with obstructions surrounding an aerodrome is essential since the great difficulty in landing during sandstorms occurs when, having flown over the aerodrome in one direction, it is necessary to turn and land in the opposite direction after the aerodrome has

disappeared from sight. This differs from a fog landing which can be made in any direction because there is usually no wind.

As I have mentioned, during sandstorms, aircraft become highly charged with static electricity, and great care must be exercised when refuelling.

Now let us proceed further East.

Between Karachi, Singapore and Darwin it will be simpler to divide the year into the two seasons—the north-east and south-west monsoons for the Karachi-Singapore section, and the north-west and south-east monsoons for the Singapore-Australia section.

During the north-east monsoon, piloting an aircraft over the Karachi-Singapore route is a comparatively easy matter. The weather is mainly fine as far as Southern Siam, visibility on an average is more than 15 miles and upper air reports giving speed and direction of the wind are available at most stations along the route. Duststorms may be encountered over the Sind Desert at this period of the year, but these are not as a rule very dense; visibility rarely falls below 1,000 yards. Morning and evening fogs occur at most aerodromes during the months November-February, but their frequency is not high and generally speaking the fog is shallow. Landing in fog on this route, however, is difficult owing to the fact that where direction finding stations exist they are generally situated at some distance from the landing ground.

Conditions for night flying are good during this period, but there are few intermediate beacons, and landmarks by night are scarce. Consequently, night flying is mainly by dead-reckoning with checks by wireless bearings. The latter cannot be relied upon because most of the stations on the route have Bellini Tozi equipment which is subject to " night error."

Across India, before and after the south-west monsoon, when very hot weather is experienced with strong westerly to south-westerly winds increasing with height, the captain is often faced with the problem of deciding whether he will remain low and in disturbed hot air of about 115° temperature or fly high into cooler and calmer air and face a head wind of about 50-60 m.p.h.

During the south-west monsoon, piloting an aircraft is a very different matter and considerable skill is called for if schedule is to be adhered to.

During this time of the year practically the whole route is covered with low cloud, and rain is constant over one sector or another. All high ground is usually in the clouds and considerable periods of instrument flying have to be carried out, and it is then that difficulties arise. One of these is that owing to the presence of low cloud and rain very few pilot balloon ascents can be made and the upper winds can only be estimated from the synoptic chart. Speed and direction of wind differ from the forecast. Again, D./F. positions are not easy to obtain when flying in heavy tropical storms when turbulent conditions make it difficult to maintain a straight course. Cumulus clouds over high ground frequently reach a height of over 15,000 feet and when flying in them one encounters severe vertical currents. Revolving storms are common in the Bay of Bengal and it is almost impossible to pass through them. Generally speaking, however, one can state that the higher the altitude the calmer the atmosphere, and even in the middle of the south-west monsoon period it is sometimes possible to fly in sunshine above the clouds at between 10,000 and 15,000 feet.

Heavy rainfall produces its own problems in connection with landing grounds, and one of the difficulties has been to find and maintain aerodromes suitable for operating heavy commercial aircraft. Credit is due to all those who have worked unceasingly to prepare and maintain runways on sites which were otherwise impossible.

This has been achieved in some places which have previously been considered impracticable, owing to the nature of the subsoil, cotton soil in particular, and this has enabled heavy aircraft to operate from these aerodromes all the year round, when all except the runway has been flooded.

The route between Singapore and Australia passes over long stretches of water and careful navigation is required. Meteorological and wireless services are not yet as good as they might be. We have a lot to learn about the upper air conditions.

Weather data east of Sourabaya is scarce, but the year over this sector may be divided into the two monsoon and two transition periods.

Owing to the presence of volcanic mountains, some of them over 7,000 feet high, large masses of cumulus cloud form over the land, producing violent thunder and rain storms—these usually occur in the afternoon.

The final sector of the route to Australia is over some 500 miles of open sea where navigation must be entirely by dead-reckoning with the possibility of "homing" on Darwin. Upper wind data is required on this last section of the route because it is possible to get a following wind in both directions if one can choose the best height at which to fly. Under present conditions, however, it would not be prudent to embark on a flight above 10/10 cloud because position checks cannot be obtained.

Practically over the whole route Singapore-Darwin upper winds vary with altitude, and this applies to other parts of the Empire routes such as Lower Egypt, Sudan to the Equator. The change of wind direction with change of altitude is of great commercial importance.

Frequently between Khartoum and the Equator, when a strong southerly wind is blowing at lower levels, a light to moderate north-easterly is available above 7,000 feet, and when a strong northerly wind exists at lower levels, comparative calm prevails above 7,000-8,000 feet.

From what I have said, it will be obvious that the profession of piloting commercial aircraft is one that makes great demands upon those who engage in it. First and foremost, it demands the highest possible standard of physical fitness, which must be maintained throughout a pilot's working life. The maintenance of the best standard of physical fitness is not compatible with indulgence and the enjoyment of all the pleasure that can be offered to the well-to-do in the present times.

The work necessarily involves absence from home and the acceptance of a routine far removed from that of the City worker who catches the 9.30 train to work every morning and the 4.30 home. The pilot of a commercial aircraft must be prepared to face, be able to support, rapid changes of climate and enjoy the variety of circumstances that residence in, and passage through, different countries involves.

Apart from these considerations, the work also involves continuous study of technical subjects, and a certain facility with mathematics and a number of scientific subjects. To reach the top of his profession, a commercial pilot should be a master of navigation, which involves considerable knowledge of mathematics, astronomy and meteorology, and those who find study irksome and mathematics distasteful, can never hope to reach the coveted positions in the air transport world.

Above all, a commercial pilot must have wise judgment and sufficient strength of mind to refuse to fly in conditions that introduce risk, even in the face of the taunts and sneers of the ignorant and foolhardy.

It was at one time thought that the business life of a commercial pilot would be comparatively short, and that it was a profession for young men only. Experience to date is causing this view to be modified, and in spite of the known liability of physical characteristics to deteriorate with age, there are already captains in Imperial Airways who have to their credit over 10,000 hours flying, and whose physical condition suggests that they are fit to continue their work for very many years to come.

There can be no doubt that piloting commercial aircraft is a man's job, and few of those who have attained to the senior positions would care to change their profession for any other.

With an annual mileage on the European and Empire services of close on four million, and a regularity percentage of completed over scheduled flights of well over 95, I think that Imperial Airways' captains and crews might well be proud of their record.

Discussion

Mr. E. C. Gordon England (*Fellow*): The President must be and at least one other member of the audience was delighted and heartened to hear an authority such as Major Brackley state that military and commercial aviation tended to diverge in their characters.

Having congratulated Major Brackley on a most excellent and thought-provoking survey of the subject, Mr. Gordon England asked whether he would favour, not only the heating of the control cabins, but also their ventilation on the latest American system, using conditioned air. That, of course, would involve more or less permanently closed cabins. Probably it was one of the finest means of securing equitable conditions for the crews, who must be prepared to give up the idea of having open windows, for open windows rendered almost impossible the proper heating and ventilation of the cabins.

Discussing rudder bar control and rudder pedals, he asked whether Major Brackley favoured the hanging rudder pedal for all types of commercial aircraft or whether he preferred the rudder bar action on the smaller types of aircraft.

Another question was where he would place the minimum limit of size of aircraft in which the automatic pilot should be adopted. Inasmuch as he had rather indicated that he looked for the adoption of the automatic pilot on larger aircraft than exists at present, did he feel that automatic pilots were not justified on the present size of aircraft? American practice was to provide automatic pilots on relatively small machines.

With regard to risk of collision in fog, Mr. Gordon England suggested that the " controlled area " system would become almost an impossibility if there were to be a considerable number of routes in Europe, for example. So far as he could see, cross routes could not be avoided in Europe, and as the number of routes increased we should require some other preventative than controlled areas. Would it not be possible to provide on the aircraft themselves a means of preventing collision—for example, a fixed setting short-wave set, working on an internationally agreed wave-length, used both as a transmitter and a receiver, with a direction device on it? It could be fitted on all aircraft, and the range would be limited merely by the speed at which civil aircraft operated; for slow aircraft the limit of range of the apparatus could be cut down, whereas for faster aircraft the range would have to be increased.

He asked also whether experiments had been carried out by Imperial Airways or anybody else with a view to overcoming the difficulties which might arise when trying to fly on instruments in a machine which was really stable. If a machine had a particular periodicity of its own and the instruments were operating at a higher periodicity, the pilot would be giving himself an undue amount of work in trying to keep the aircraft on what the pilot maintained was the normal course, whereas the aircraft, if left to itself, would be obviously at variance with the instruments at certain moments, but would carry on fairly well. He believed it had been found in America that the automatic pilot was so sensitive and rapid in action that it preferred to operate on a machine the stability of which was not too rigid. He had been told on good authority that the passengers in American machines could tell immediately whether a machine was being flown by the automatic pilot or by human hands—and apparently the preference was for the automatic pilot.

Bearing in mind the comfort of pilots, he asked whether there was any real importance in the question concerning the plane of the propeller disc relative to the eye of the pilot, or whether that was quite a secondary consideration. It had been mentioned to him on several occasions that it was becoming increasingly important, particularly for night flying.

Major Brackley's views on the useful life of pilots were of great interest. It would appear, from his remarks, that physical fitness must of necessity become a secondary consideration. Mr. Gordon England suggested that knowledge and experience were the real controlling factors in assessing the value of a senior pilot to any air line, and that it was a matter of greater concern to the passengers to know that they were in the hands of a thoroughly competent and experienced pilot than to know that they were in the hands of one who was merely physically fit. Surely, he said, now that a commercial aircraft carried a second pilot, and bearing in mind that aircraft of the future would be even more foolproof than that of to-day, physical fitness was relegated to a secondary position, and the fitness of a pilot for his job should be governed mainly by his experience.

Mr. S. H. Evans (*Member and Associate Fellow*): What was being done concerning de-icing equipment on commercial machines? This country, he said, seemed to be very backward in that respect, although he understood they were conducting long-range research into the problem for the benefit of the next generation of aircraft designers. Meanwhile, American air lines had fitted the Goodrich de-icer for the past year or two, and just went on flying them in active service. He had seen them some three years ago as regular equipment on the Northrop " Alpha " mail planes of T.W.A., and he believed they were now standard equipment on the Boeing and Douglas transports. However, he supposed it would prove well nigh impossible to de-ice completely many of Imperial's present flying stock, due to the presence of external bracing and control wires, so dear to the heart of their maintenance engineers in the past. The case for the cantilever monoplane needed no further advocacy than this problem of ice accretion.

Lord Sempill (*Fellow, Past-President*): Having travelled recently over the largest section of the route referred to in the paper, he said he could support all Major Brackley had said regarding conditions met with.

The precise words used in the paper concerning the automatic pilot were that the lecturer regarded it as desirable equipment in the larger types of aircraft that were to be used; and he had pointed out that the controlling factors were weight and cost. Would he be prepared to modify that wording and to say that, assuming an automatic pilot could be produced having a weight which he would consider reasonable, it would become, and in fact must become, an essential fitment in all commercial aircraft in the future?

Commenting on the statement that the artificial horizon and the directional gyro were fitted as standard instruments in all Imperial Airways aircraft, Lord Sempill asked for Major Brackley's experience concerning the three different methods that could be used for operating those instruments. Had the Venturi drive been completely outclassed by the mechanical? Another question was whether Major Brackley did not consider it necessary to duplicate completely instruments like the artificial horizon, as being one of the most vital instruments?

Again, did he not favour the altimeter which was now standard on most modern American commercial aircraft, and which allowed of rapid barometric correction as soon as the pressure on the ground had been ascertained?

Captain F. Dismore (Imperial Airways pilot): Commenting on the point made in the paper that a minimum safe visibility when approaching to land was 300 yards and that a pilot should not leave the ground when visibility was less than that, he suggested that that was rather a short distance, and that 500 yards was safer as a minimum.

Mr. H. E. WIMPERIS (*Fellow*, Director of Scientific Research, Air Ministry): He felt that Major Brackley must be very proud of the record of Imperial Airways in respect of comfort, security and freedom from undue noise. The company's record was splendid, and one hoped that it would for long be retained.

Discussing flight and landing under conditions of poor visibility—not necessarily in fog, because that represented the extreme condition, and the difficulties of the intermediate condition had to be solved first, if possible—Mr. Wimperis said there were many methods in use, in the United States and on the Continent of Europe, for aiding aircraft when operating in such conditions to find the route, to approach the aerodrome and to land. He asked which of the many schemes Major Brackley considered possessed the best qualities and was likely to be adopted universally. He spoke of universal adoption, meaning in the first instance universal in Europe, because he could hardly conceive of each country having its own particular system; the apparatus which it would be necessary to carry under those circumstances would become absurd in amount. As a supplementary question, Mr. Wimperis asked what specification Major Brackley would put forward as representing the ideal.

In response to a remark by the President, Mr. Wimperis stated that he recently attended with other representatives of Great Britain, as the guests of the Royal Academy of Italy, a discussion on flying in the stratosphere, a discussion contributed to by the chief authorities on aerodynamics, such as Prandtl and Von Kármán, and he felt that he had learned a lot by discussion with those authorities. At the same time, he could not say that they had proceeded a great deal further in regard to stratosphere flying, though he mentioned that the papers which had dealt more particularly with the future had come chiefly from Italian sources and had dealt quite readily and easily with heights of 20,000 metres (60,000ft.) and speeds of the order of 2,000 kilometres per hour. That the authors of such papers were looking far ahead could be appreciated by reference to the fact that, so far as could be seen by the wisest he had been able to consult, a flight at 60,000ft. would involve a departure from the piston type of internal combustion engine altogether and the production at some stage, by somebody, somewhere, of a totally new form of prime mover to cope with the particular conditions subsisting at such altitudes. Work in that direction was said to be in hand in various countries, but Mr. Wimperis doubted whether it had yet been tackled very seriously anywhere, because he believed that no one had yet seen a means of making prime movers which would take machines up through the troposphere and still be suitable for flying in the stratosphere.

Captain C. F. UWINS (*Associate Fellow*): The fact that he had been into the stratosphere on one or two occasions had strengthened his belief that commercial flying would not realise that ambition for very many years to come.

Discussing the disappointing experience of Imperial Airways when engaging pilots, that they were not capable of flying by instruments, he said that that was probably due to the method of training most of the club and Service pilots. A turn and bank indicator and a spin indicator were used, and they were far from satisfactory; the main concern governing their use was to enable a pilot to recover from a spin. Instruments such as the artificial horizon and the directional gyro, however, prevented a machine getting into a spin; so that the Service type of training should never be of any use to a commercial pilot. He asked if Major Brackley knew anything of the Boeing method of instruction in blind flying; he believed it was the custom to give a pilot 80 hours' blind flying before he learned ordinary flying. Had Imperial Airways a scheme whereby part of the cockpit was closed during flight so that a pilot could practise blind flying if conditions were good, the second pilot maintaining a look-out at the same time?

With machines of very high cruising speeds that one might envisage in the near future there might be difficulty in approaching aerodromes in conditions of

low visibility. He asked the highest speeds at which machines should be capable of approaching an aerodrome under full control in order to land safely under those bad conditions?

Captain A. S. WILCOCKSON (Imperial Airways): With regard to the rapidity of action of blind flying instruments, he suggested that the time lag occurring in the operation of big aircraft was partly the reason why young pilots experienced difficulty in blind flying. In big aircraft there was a definite lag; one would find that a machine was going down, as indicated by the instrument, and after one had pulled the stick back one would find the nose still going down for quite a period before it would commence the reverse action and rise again. There was a similar lag when bringing the nose down again. It was difficult, therefore, to follow the instruments, because owing to the lag one more or less caused the machine to hunt quite considerably. One needed quite a lot of experience in order to get the hang of flying under those conditions. The problem was very serious, because it meant that one had to learn to fly each particular aircraft blind in a different manner from other aircraft, each having its own peculiarities.

Major R. H. MAYO (*Fellow*): Having been responsible, as Chairman of the Lectures Committee of the Society, for Major Brackley's presence on this occasion, he claimed that he had already made thereby a very important contribution to the Proceedings. Major Brackley was elusive and it had been difficult to secure his presence—not because he was unwilling to come, but because he was so often making journeys to Australia or South Africa or spending a week-end in travelling to India and back in the course of his duties! That was the reason why he had not been able to present this paper before.

The paper served to emphasise, continued Major Mayo, how enormously the status of the so-called "pilot" had improved during the last fifteen years. When one considered the heavy responsibilities borne by the present-day captain of an air liner one realised what an immense amount of training was required and what a high type of man was required to fill such a post. One could foresee that that process would continue in the future, and that in course of time the captain of an air liner would not handle the controls at all, but would have under his command a crew consisting of a chief pilot, a second pilot, and so on, his own duty being to command the air liner in the same way as did the captain of a sea-going liner. His responsibilities would be to see that everything was done properly and to take decisions as to navigation, etc.

Captain H. H. PERRY (Imperial Airways): He did not know whether or not it was the intention to fit the automatic pilot to the company's machines, but he did not think it was essential for machines to be so fitted for operating short routes. It was all very well for long distance work, but people seemed to be of the opinion that a human pilot in control of a machine gave the passengers more comfort than did the automatic pilot. But, of course, much depended on the type of aircraft. He, personally, would rather handle the machine over the short distances he was operating than use an automatic pilot.

Mr. A. J. HUGHES (*Associate Fellow*): He was very interested in the nautical flavour which Major Brackley had introduced. Speaking with some experience of marine navigation, he said it should always be borne in mind that the captain of a ship was the best navigator in the ship; that state of affairs should apply also to aircraft. He had been very much impressed by Major Brackley's references to the defects in wireless bearings, and asked what percentage of good bearings was obtained in aircraft. The amount of good direction bearings obtained at sea was often very poor; one could not say that a good bearing was obtained every time at sea. Indeed, he had often been on the bridge of a ship when over a period of many hours the captain had rejected wireless bearings for one reason or another. Nevertheless, they continued to take wireless bearings and checked them constantly by dead reckoning.

He believed that the Royal Air Force automatic pilot was the very best in the world—it gave definitely very much better results than the American. He had had some experience recently of the use of the American automatic pilot in a Douglas machine, which, he believed, was an unstable machine. Soon after the automatic pilot had locked in—and he could not determine that exactly, however closely he had watched—it had distinctly set up a weaving motion. That might have been due to the Douglas machine, but he believed it to be due rather to the amount of control which the particular automatic pilot used had exerted over the aircraft. His opinion was that the automatic pilot, if properly applied to Imperial Airways machines, would contribute very much to the comfort of passengers and would also give good results in directional flying. It was rather unfortunate that the American pilots used the automatic pilot more to give themselves a rest than as a means to steer the ship, and he hoped that in future Imperial Airways would give attention to the question as to whether the automatic pilot could be used for actually steering the aircraft.

Reply to Discussion

Replying to Mr. Gordon England, Imperial Airways had not tried the enclosed control cabin ventilated by the latest American conditioned air system, but would like to try it and might have the opportunity in the new Empire fleet. Due consideration was being given to the heating of the cabins, and, of course, to ventilation. One of the difficulties he foresaw was in keeping the windscreen clear when the cabin was heated, because the difference between the inside and outside temperatures might produce a mist.

Imperial Airways had not much experience of the automatic pilot in their present-day fleet, perhaps because the aircraft were not designed to take the automatic pilot—the control system must be designed specially for that purpose. But they were allowing for it in their new aircraft and were hoping to try out more than one type of automatic pilot shortly.

One of the drawbacks of the automatic pilot was that it made jerky movements. He believed that pilots would much prefer to control the aircraft themselves, especially when air conditions were turbulent. The automatic pilot was rather rough on the controls; no matter how one regarded the matter, there was nothing like the touch of the human hand. The automatic pilot operated only *after* the aircraft had altered its position, whereas the human pilot could sense the required amount of correction on the controls.

Dealing with Mr. Gordon England's criticism of the controlled areas system in preventing collisions, and his question as to whether anything effective had yet been found to warn an aircraft that another aircraft was in its vicinity, he said there were several ideas being developed and he was not sure whether any of them had yet reached the market. The one which seemed to lend itself best to further investigation was designed, he believed, by Dr. Robinson, who had also designed the homing device. The control was to be effected by wireless, which emitted a certain note. When another aircraft came within its range it would indicate the direction in which it lay and would also give some idea of its height. It must be assumed, of course, that all aircraft would be fitted with it. However, Dr. Robinson was working on such lines, and believed that his work would be successful.

The difficulty Mr. Gordon England had suggested concerning the propeller disc, especially during night flying, applied particularly to single-engined aircraft; if the propeller were coloured dull black, the difficulty would probably be overcome, in his experience. Presumably Mr. Gordon England had in mind that a landing light or a light situated perhaps in the wing would reflect on the propeller.

Mr. Gordon England agreed.

Major Brackley, continuing, said that no one realised more than did Imperial Airways the tremendous experience stored up by their senior captains of to-day.

His point in raising the question of physical fitness was that, although the senior captains had the experience, they must also watch their health, for they had still to withstand rapid changes of climate and temperature. Mr. Gordon England was quite right in assuming that Imperial Airways hoped their senior captains would remain with the company for many years, because their experience could not be replaced.

In reply to Mr. Evans, he said that Imperial Airways had investigated all the de-icing equipments on the market, but had not tried them on the aircraft because it had not been possible to fit them. It was a very difficult problem, the difficulties applying to the biplane being different from those applying to the monoplane, and he doubted very much that it was worth while doing anything in that direction on present-day aircraft. For future aircraft they would have to find an efficient means of preventing ice formation on the leading edges or on other excrescences.

Replying to Lord Sempill, he considered that it would be advisable to use a smaller automatic pilot, if available, so reducing weight, and he hoped that if Lord Sempill knew of one, he would indicate it, so that if possible it could be tried out on the company's larger aircraft without reconstructing the whole of the control layout.

The company had not duplicated instruments such as the artificial horizon on the present fleet, but on the future fleet all the essential navigating instruments would be duplicated and operated mechanically.

They had tried out, of course, the very well known and very popular sensitive altimeter of American manufacture, and were very pleased with it. But Major Brackley pointed out that all the company's aneroids were graduated to the millibar scales, so that a pilot could adjust his altimeter according to the barometric pressure, about which he was informed by wireless.

Dealing with the remarks of Captain Dismore with regard to landing in conditions of low visibility, as in a sand storm, he said that he personally had experienced landing when visibility was only 300 yards, and probably even less, and many of the senior captains operating the Empire routes had landed their aircraft when visibility was less than 300 yards. It was a question of vertical visibility very largely. Once a pilot had reached the vicinity of an aerodrome whose surroundings he knew intimately, he knew exactly how he could approach it. If he were not familiar with the aerodrome surroundings, it was better that he should not attempt to fly under such conditions.

Dealing with the question put by Mr. Wimperis as to the best method that could be adopted universally for landing in conditions of low visibility, Major Brackley said he was perhaps fortunate in being chairman of a small committee set up by the International Air Traffic Association, which committee held meetings in various countries and studied the methods of landing under conditions of poor visibility. The Germans had produced an ultra short wave landing device, which he believed was regarded as a commercial possibility; their pilots were trained to use it, and they could use it 99 times out of 100 with perfect safety. That particular system had been adopted on the most important German aerodromes, the German aircraft being fitted with a nine-metre receiver. In addition, the Swiss, and he believed the Dutch, companies were adopting the system, and, needless to say, Imperial Airways would try it as soon as they had the necessary ground equipment. It might be necessary to instal it first on the aircraft operating to and through Germany, and it was hoped to do so this winter. The request that he should indicate what he would specify as the ideal for universal adoption was rather a tall order, and he would prefer a little more notice of that request. But he would aim at simplicity first, for he would be anxious to make it as easy as possible for the pilot. The German system seemed to be as complete as a system could be; the ability to use it must be acquired by practice. He was told that most of the German and Swiss pilots were able

to land by the aid of that system after less than one hour's instruction. He had been on board both German and Swiss aircraft during experimental landings, under the hood, by the aid of that system. If one listened and watched the instruments closely, one noted that all indications were given correctly, the approach beacon and the aerodrome boundary beacon were indicated very clearly, both aurally and visually. Once the machine passed the boundary beacon, one landed in the normal way, the aircraft coming to rest on the white line in the middle of the aerodrome.

Replying to Captain Uwins, he did not know of the Boeing system of training in instrument flying, and was rather surprised to hear from Captain Uwin that a man who had never flown before was taught to fly first by instruments, under the hood, for 80 hours, and was then regarded as a fully-trained instrument pilot. Such a man must know quite a lot about instrument flying after 80 hours, and his confidence should be great.

The enclosing of part of the control cabin had been tried out quite a lot; and when pilots had been faced with the Air Ministry notice that they must go through a blind flying course or their licences would not be renewed, he believed many had stuck paper on the windscreen to practice instrument flying.

As to the effect of the higher speeds of future machines upon their ability to land when visibility was as low as 300 yards, Major Brackley suggested that, whatever the speed of future aircraft, their speed range should be such that their landing speed was reduced to something equivalent to that of present-day aircraft. He did not think that future aircraft would land at a speed in excess of 100 m.p.h.

Captain Wilcockson had explained clearly the question of lag in the operation of the larger aircraft, and the fact that the instruments indicated what was happening before the aircraft controls were effective.

In reply to Mr. Hughes' question concerning defects in wireless bearings, Major Brackley claimed that the percentage of first class bearings given was very high. When the ground stations were not absolutely certain they would not guarantee it, but would either indicate that it was second class or would ask for the transmission to be repeated, so that they could take another bearing. Alternatively, another station could try taking a bearing.

With regard to the statement that the American automatic pilot was not so good as the R.A.E. type, he said there were many American automatic pilots in use, and he did not know how many there were of the R.A.E. type. There ought to be more types on the market, so that they could be tried out. He, personally, had no doubt that the human pilot could control the aircraft in a much nicer way than could the automatic pilot.

The PRESIDENT: In proposing a vote of thanks to Major Brackley for his paper, he expressed his delight that the view that physical fitness varied inversely with age had been dismissed, and said it was very pleasing to know that they were not to have too young pilots in commercial aircraft. Not only had the characters of military and commercial aircraft diverged, but the idea of always engaging ex-R.A.F. officers as pilots of commercial aircraft was also exploded. Such a practice seemed akin to employing ex-cavalry officers to drive motor buses. The piloting of military and commercial aircraft were quite different propositions, and he was glad that Imperial Airways had taken that view.

He had been delighted also to hear from Major Brackley that the comfort of the passengers was a consideration which influenced largely the conduct of commercial aircraft pilots; and, of course, that was one of the important considerations if an air line were to make money. If aircraft were very uncomfortable, people would not tolerate it. Some of the journeys to Africa were only just tolerable to the old sea salt; to the bad sea sailor they were just impossible.

When listening to the reading of the paper he had been impressed by the fact that they still suffered from a lack of knowledge of meteorology; one

became more and more impressed by that fact as aircraft routes were extended through the various parts of the earth. Meteorologists were very touchy about this. He recalled having remarked on one occasion that it was odd that they could forecast exactly an eclipse 100 years hence, whereas they could not advise anyone on any particular morning whether or not it was necessary to carry an umbrella during the afternoon of the same day. That was almost the position, and the more we concentrated on meteorology the greater would be the benefit derived by the man in the street as well as by the aviator.

If stratosphere flying were to lead to a new type of engine for aircraft, it would be almost doubly welcome. In the early days, whenever an engine had broken down, as it did invariably after 40 seconds, his old friend Voisin would curse, in the most amazing language, the " ces sales moteurs à explosion." Every motor which was liable to explosion was, in the President's view, a " sale " motor. It must not be thought, he said, that commercial aviation thirty years hence would be anything like the commercial aviation of to-day; the prime mover and everything else would be different in the future. Changes were being made so rapidly, and if the remarks that had been made at this meeting were repeated thirty years hence, the speakers would all be certified as lunatics. Often the technicians got into a rut and imagined that everything would remain the same for ever, but it would not. He would welcome very much a different power unit, a different form of propulsion—even if it did squirt gases backwards at 60,000ft.

The Society, he concluded, was grateful to Major Brackley for his clearness in exposition and delivery, and for the great work he had done for commercial aviation for England.

The 597th Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

A meeting of the Royal Aeronautical Society was held in the Lecture Theatre of the Institution of Electrical Engineers, at Savoy Place, Victoria Embankment, London, W.C., on Monday, November 18th, 1935, the President (Lieut.-Colonel J. T. C. Moore-Brabazon) in the chair.

A paper on "Cooling Problems, with Particular Reference to the Work of the 24ft. R.A.E. Tunnel," was presented by Dr. G. P. Douglas.

The PRESIDENT: From 1916 to 1919 Dr. Douglas had been engaged at the Royal Aircraft Establishment on model and full-scale experiments with Mr. McKinnon Wood, Professor Southwell and Mr. Farren. Since that date, until 1934, he had been in charge of wind tunnel experiments there and was now in charge of the Aerodynamics Department.

Dr. Douglas had said that he would have preferred to have given his lecture six months hence. The President considered it desirable, however, that the data obtained so far from wind tunnel experiments should be put forward, because one could be certain that if the Society had waited another six months for the data, Dr. Douglas would have required still another six months in which to digest the data obtained during the intervening six months. The Society welcomed the opportunity to hear the latest information obtained from the latest wind tunnel.

COOLING PROBLEMS, WITH PARTICULAR REFERENCE TO THE WORK OF THE 24FT. R.A.E. TUNNEL

BY

G. P. DOUGLAS, M.C., D.Sc., A.F.R.Ae.S.

Cooling problems have recently been occupying a considerable portion of the time of the Aerodynamics Department at the Royal Aircraft Establishment. The work had hitherto been of a theoretical nature combined with tests in the small tunnels. The new 24ft. tunnel has provided us with a very valuable piece of apparatus to deal with the problem. The work is proceeding and is still incomplete, but we are beginning to have a clear idea of the principles involved. In this lecture I propose to describe briefly the tunnel and its working and the work we have been doing in it. The lecture is given by permission of the Director of Scientific Research, Air Ministry, but the views expressed represent only my own opinions.

PART I. THE 24FT. TUNNEL

Detailed accounts of the tunnel and its equipment have already appeared in the technical Press, notably the excellent article by Dr. Chalmers, in *The Engineer*, and I shall merely remind you of the leading features of the tunnel design.

When we were preparing the scheme for this tunnel, no tunnel of the open jet type had been built in this country and very careful model experiments were

made. First we built a model with working section one foot diameter and experimented until the flow was to our satisfaction. This one foot tunnel has since proved very useful and was used for the ice formation experiments described to you in the last lecture. This tunnel was then reproduced in its essential features to five times the scale and thoroughly tested. The resulting design fitted with a 500 h.p. motor gives us a very useful tunnel with a speed of 215 miles per hour. The 24ft. tunnel reproduces the 5ft. design to an increased scale.

The leading features are:—

Jet diameter	24ft.
Length of jet	44ft.
Collector dia. (maximum)	40ft.
Fan diameter	30ft.
Length of centre line of return circuit	356ft.
Contraction ratio: (max. area/jet area)	3·53 : 1
Max. h.p. of fan motor	2,000 h.p.
Max. tunnel speed	115 m.p.h.

The building is of steel and ferro-concrete construction, and includes an aeroplane erecting shed to one side of the open jet (Fig. 1), and a tower above the jet containing a lift which carries the balances from which models are hung (Fig. 2), and containing the model rigging bays. This will allow models to be lowered into the jet, when there is a pause in full-scale work.

Since aeroplanes can be tested with their engines running, ventilation is provided, in order that the concentration of carbon monoxide in the exhaust gases shall not reach a dangerous proportion of the air circulating round the tunnel. Fresh air is let into the building through an annular space concentric with the nozzle (Figs. 3 and 4). The lip of the collector is perforated, and air can be exhausted to the outside of the building by four extractor fans at a rate of 0.25×10^6 c. ft. per minute.

A wire mesh fan guard consisting of 16 gauge steel wire in 6-inch mesh was erected in the collector in front of the fan, to prevent objects from blowing into the collector and hitting the fan (Fig. 3).

In the floor of the working section, a pit accommodates the main balance (Fig. 4); this is of weighbridge type, and measures lift up to 8,000lb. and drag from $\pm$4,000lb. simultaneously. The load can be balanced out by jockey weights to the nearest 100lb. and the remaining out of balance load can be read from an illuminated scale. The balance frame has three attachment points to take the feet of the pylon structure on which the aeroplanes are mounted before they are swung on to the balance by means of a jib crane.

Large scale models are slung from an overhead balance. Immediately above the working section there is an opening in the ceiling 20ft. by 18ft. 8in. through which the model, mounted on its balance car, can be lowered into the jet. The model bay above the working section is shown in Fig. 2.

The fan motor speed is controlled by a coarse and a fine control, the former operated by hand, and the latter by an automatic control device governed by the wind speed.

Tests on Complete Aeroplanes

The working section of the tunnel is large enough to accommodate an aeroplane of 50ft. span, but only the centre portion is in the air jet, and the tests are confined to the effect of modifications to this centre portion. It is conceivable that the method might give misleading results owing to the limited jet. The change in the load distribution, due to a change in design, might be influenced by the jet boundary, or the change in design might modify the jet boundary itself.

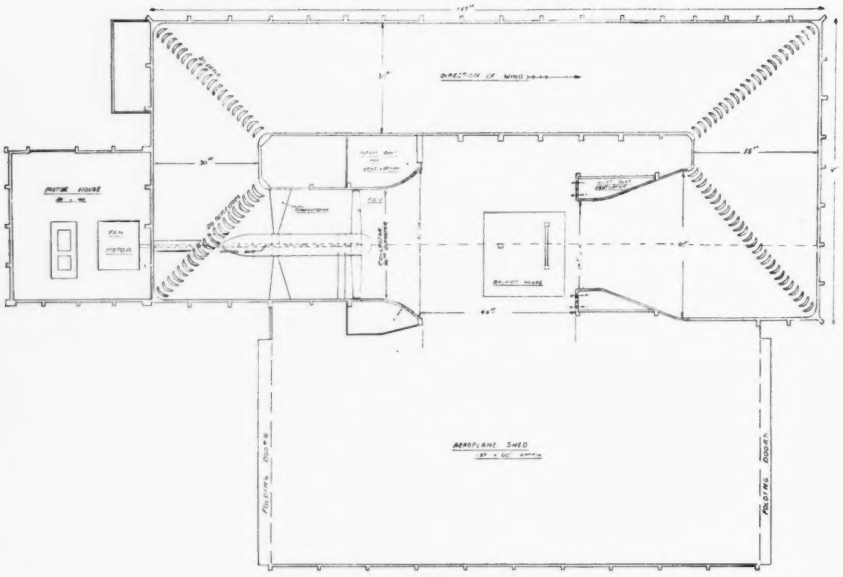


FIG. 1. *R.A.F. copyright reserved.*

Erecting shed, general plan.

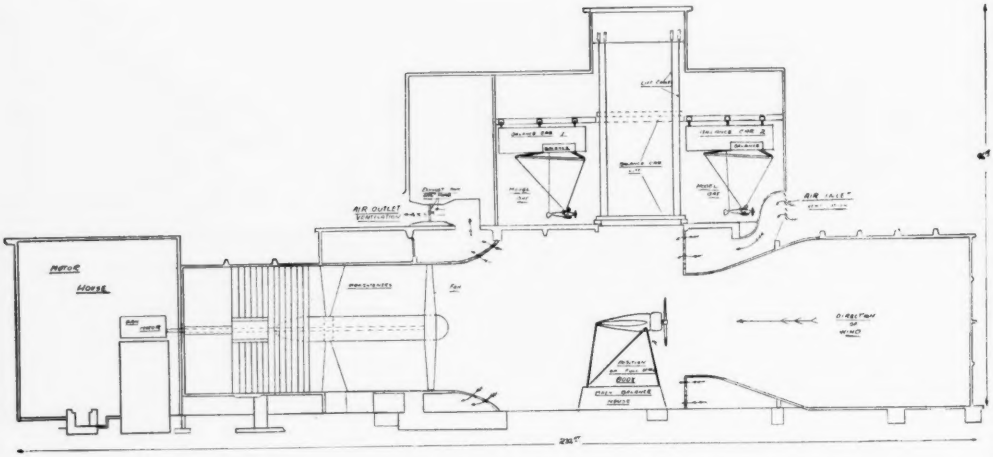


FIG. 2. *R.A.F. copyright reserved.*

Section showing model lift and ventilation scheme.

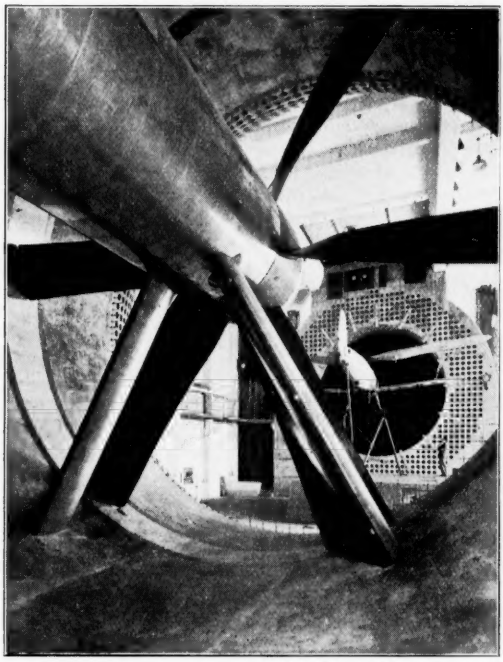


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FIG. 3.
View through fan, showing wire screen.

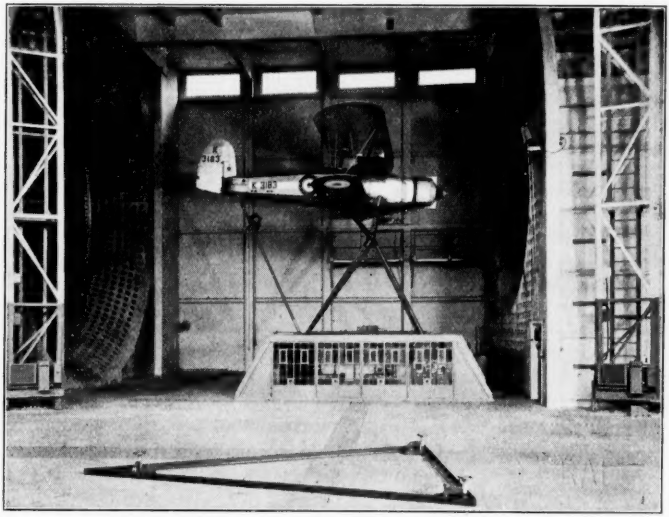

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FIG. 4.
Working section, showing balance pit.

To check the validity of the method, comparative tests were made on a Bristol Fighter model of 8ft. span in the 5ft. open jet tunnel mentioned above, and in the N.P.L. Duplex tunnel, which has an airstream of 7ft. x 14ft. The quantity measured was the effective thrust of the airscrew and the tests were made at the incidences corresponding to no lift, maximum level speed and climb.

The results are given in Fig. 5, and it is evident that the effective thrust of the airscrew deduced from measurements in the open jet is in complete agreement with that from the Duplex tests. We had expected agreement at the lower lift coefficients, but were surprised at the complete agreement at the higher lift coefficients.

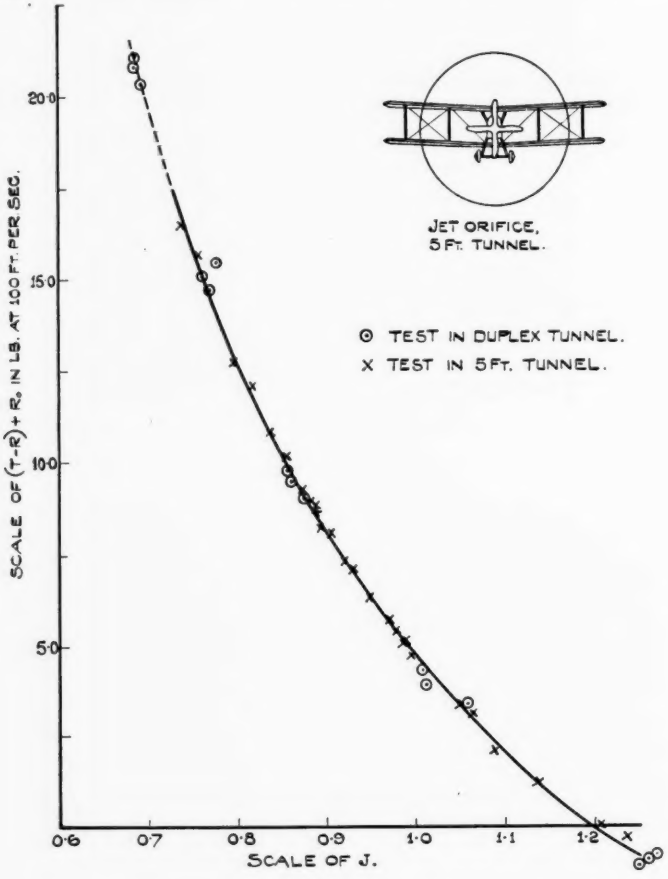


FIG. 5.

Tests on $\frac{1}{5}$th scale Bristol Fighter.
Comparison of effective thrust measured in open jet and duplex tunnels.

The influence of the airscrew which was 0.4 of the jet diameter on the jet boundary was also investigated in a plane 0.5 of the airscrew diameter behind the airscrew. No change could be detected.

The Pulsation Problem

Open jet tunnels are liable to pulsate. The actual phenomena are complicated, but the broad explanation is probably as follows. When an air jet is passing through still air the boundary is unstable, and vortex rings are formed which behave as if they were roller bearings between the jet and the still air, and move downstream at about half the jet velocity. As each vortex ring approaches its image in the collector it is deflected radially, giving rise to a pressure pulse. This pulse is liable to start a new vortex ring from the nozzle. We thus have a periodic occurrence, the period being approximately $2L/VN$, when V is the jet speed, L the length of the working section and N an integer corresponding to the number of rings in motion between nozzle and collector.

These various oscillations would in themselves be unimportant, but when any one of them is coupled to a resonator of suitable frequency, oscillations of large amplitude may result. In a tunnel of the type we are considering, the return circuit can resonate as a tube with both ends open and it usually resonates with two nodes as indicated (Fig. 6). A cure can be effected either by introducing

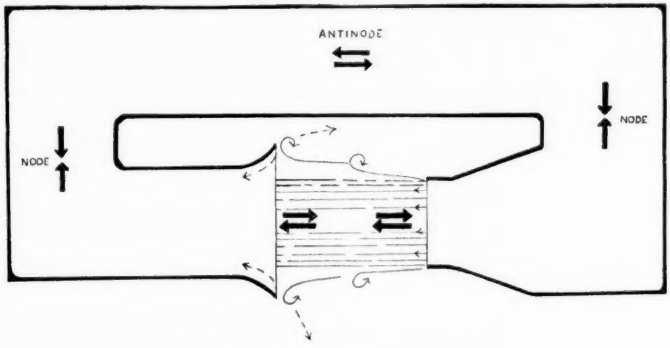


DIAGRAM ILLUSTRATING PULSATIONS.

FIG. 6.

leaks near one of the nodes to damp the resonating properties of the return circuit, or by fitting tabs to break up the jet surface and prevent the formation of large vortex rings.

Serious pulsations occurred when the 24ft. tunnel was first run. The flow was observed by watching airspeed indicators connected to a point at the nozzle mouth in the centre of the jet, and also to the static pressure hole. At the centre of the jet fluctuations were observed at 50 m.p.h.; at a mean speed of 80 m.p.h. 4 m.p.h. fluctuations were recorded, and 8 m.p.h. fluctuations at 100 m.p.h. The frequency of the fluctuations was 2.8 per second at 80 m.p.h. when an audible beat of this period was heard. This increased in intensity, and severe vibrations occurred in many parts of the building as the speed was raised.

Fifteen tabs were then fitted in the mouth of the nozzle. A recording manometer was connected to the static pressure hole, and a continuous photographic record of pressure was made at various tunnel speeds with the tabs projecting 3in., 6in., or 9in. into the jet. Without tabs, the fluctuation was equivalent to variations of 15 m.p.h. at a mean tunnel speed of 80 m.p.h. With tabs, part of the films showing the fluctuations are reproduced in Fig. 7, showing that 6-inch tabs give reasonably steady conditions. The audible beat and vibration of the building were stopped, and the variation of speed in the jet was less than 1 m.p.h. at all speeds.

No difference could be detected in the power factor of the tunnel on adding tabs.

Calibration of Tunnel

Fitting the tabs has affected the distribution of static pressure along the tunnel axis, since the nozzle was designed to make this constant without tabs. In consequence, the mean velocity in the central 20ft. of the tunnel increases as the distance from the nozzle increases. The velocity rises 1.3 per cent. in a length equal to one jet diameter. When time permits, tests of alternative methods of improving the steadiness of the flow will be considered.

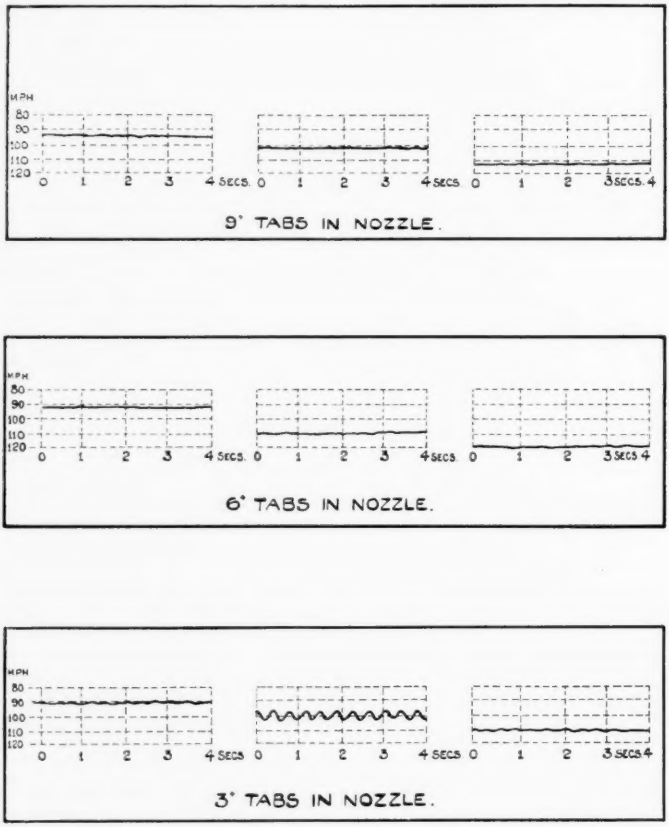


FIG. 7.

The pressures at the static hole in the tunnel wall as recorded by a continuous recording A.S.I.

The velocity distribution in any one section lies within 1½ per cent. of the mean value over the central 20ft. diameter, and does not change appreciably as the speed is varied.

Critical Review of Design

The tunnel as built represents a very useful piece of apparatus. To keep down building costs, the return circuit was made as compact as possible, with a

contraction ratio of $3\frac{1}{2}$ to 1. A slight increase would give more margin for errors in design. It is probably best to place the fan immediately behind the working section in an open working section tunnel. The uneven distribution after the open jet is immediately corrected, and the disturbance due to the model is partially evened out before the air goes round the first set of deflector aerofoils.

One question asked in connection with this tunnel is why it is not of the double return type. It is suggested that a single return tunnel must give poor velocity distribution because the air which has been following the long outer wall must have suffered a much greater loss in energy than the air which followed the short inner wall. Actually there is a secondary flow at each set of deflector aerofoils which transfers de-energised air from the outer to the inner wall and provides automatic compensation. Further, the double return is liable to produce a section of tired air in the middle of the test section; and it makes access to the working section difficult.

The second question is why was not the tunnel made bigger and why was the speed limited to 115 m.p.h. A tunnel to test even the smaller of the best service aircraft under maximum speed conditions would require twice the cross section and at least three times the speed, so that instead of the present 2,000 h.p. for the fan, 100,000 h.p. would be required. Increase of size leads to reduction in sensitivity of balances and increased time on rigging and repair. The tunnel built represents a very convenient compromise for the type of work for which it is intended.

Part II. Cooling Problems

The possibility of increasing speed has forced into the foreground the question of engine drag. We were considering recently the design of a commercial aeroplane suitable for the Atlantic passage, fitted with four 600 h.p. radial engines. If the drag per engine be taken at the very moderate figure of 15lb. at 100 ft./sec., we find that at 265 miles per hour one of the engines is merely serving to neutralise the drag of the other three. If we could get rid of the engine drag the fourth engine would have been unnecessary, and all its weight and petrol would be available as pay load. If we consider still higher speeds and the 15lb. figure could not be reduced, we find that at 380 miles per hour the whole thrust would be required to overcome the engine drag.

A few years ago, when the Schneider Trophy aircraft had to be cooled at very high speeds the surface of the aircraft was used to dissipate the heat. The installation is heavy, and although there is a lack of experimental evidence we suspect that the heating of the aeroplane skin does increase its drag. The hot surface raises the temperature of the boundary layer and hence its viscosity, so that a 100° rise in temperature of the surface would increase the skin friction drag about 4 per cent. The power required to overcome a 4 per cent. increase in skin friction of the heated surface at 400 m.p.h. is comparable with the power expended in overcoming the total skin friction of a separate radiator having five times the cooling area and with a cooling velocity of one-fifth of the flight speed. The result, therefore, appears to be little better than could be achieved by an efficient system of low velocity duct cooling.

The importance of weight must be kept in mind. We can consider how much weight we would be justified in adding to achieve a given reduction in drag in an aircraft primarily designed for speed. Consider two aircraft of given loading (w) and power, having the same maximum speed in level flight (V). They will have the same thrust given by:—

$$T = k_{Dw}\rho\,(W/w)\,V^2 + D_0\,(\rho/\rho_0)\,(V/100)^2$$

where W is the total weight, k_{Dw} the drag coefficient of unit wing surface and D_0 the extra to wing drag at 100 f./s. The first term on the right hand side is

the wing drag and the second term the extra to wing drag. The only variables are W and D_0, and differentiating :—

$$dW/dD_0 = -w/k_{Dw}\rho_0 100^2.$$

Thus if the loading be 24lb./sq. ft. and k_{Dw} be 0.004

$$dW/dD_0 \simeq 250.$$

Thus a reduction in drag of 1lb. at 100ft./sec. would justify an increase in total weight of 250lb. If we are considering a given fitting, about half this value might be taken, since in order to meet the specified conditions, the structure and wing weight of the aircraft would be increased by a similar amount to carry the fitting.

Cooling Drag

The net power required to cool an engine at low speeds is the product of the air flow through the cooling system and the pressure drop. For a liquid-cooled engine this power can be reduced indefinitely by making the radiator big enough, but using a radiator of reasonable size (say 40 calibres with an air speed 60 miles per hour in front of the radiator), the loss would be between 1 and 2 per cent. of the b.h.p. In the case of an air-cooled system the answer is less definite, but the loss is probably about 2 or 3 per cent. The value depends on the permissible cylinder temperature, and with the deep fins now employed an increase in cooling speed produces only a small increase in cooling, in fact to drop the temperature 25° the cooling power must be doubled.

If these low percentage cooling losses are to be maintained to high speeds, and the absurd losses of the previous paragraph avoided, we must have an efficient duct system in which the speed of the cooling air is reduced to that required for efficient cooling, and is discharged again without spoiling the flow round the aircraft.

The Theory of Duct Design (Fig. 8)

The theory of duct cooling has been developed independently by Capon and by Meredith, but I shall only mention the leading principles in this paper.

Consider any cooling system enclosed in a cowl whose " profile " drag is neglected. If H be the dynamic head of the outside stream and h the loss of head due to the engine or radiator which we regard as an actuator disc analogous to the actuator disc used in the theory of airscrews, then by Bernoulli's equation for any stream tube :—

$$p_0 + \tfrac{1}{2}\rho V^2 = h + p_0 + \tfrac{1}{2}\rho V_2^2$$
$$\text{or } H - h = \tfrac{1}{2}\rho V_2^2.$$

By considering the momentum in the wake the drag* must be :—

$$D = \rho Q (V - V_2)$$

where Q is the rate of flow.

The work down in cooling is hQ, and the drag power expended is DV, so that the efficiency is given by :—

$$\eta = hQ/DV$$
$$= hQ/\{\rho QV(V - V_2)\}$$
$$= (h/2H)\,1/\{1 - \sqrt{(1 - h/H)}\}$$

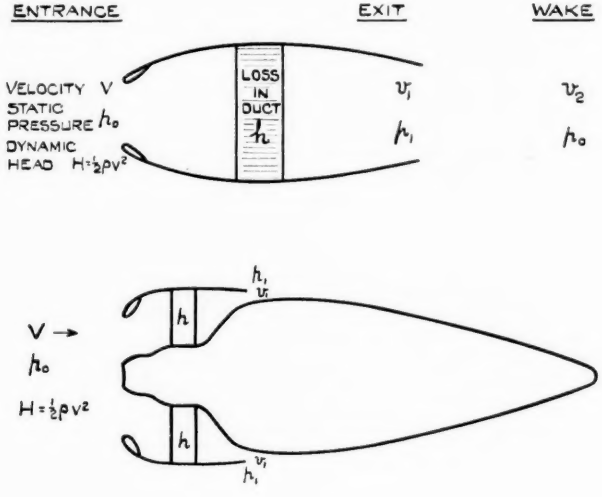
The table shows the variation of η with h/H :—

h/H	0.2	0.4	0.6	0.8
η	0.95	0.87	0.82	0.73

This very important relationship, due to Meredith, enables us to compare the drag cost of any cooling system with that which is theoretically possible.

* This is the minimum theoretical drag for the internal and wake losses of the cooling system, and to this must be added any spoiling drag and any drag due to increased external surface.

If for a given installation we regard the cooling pressure loss as constant, it appears that good efficiencies are possible over a wide range of flight speeds. At low values of h/H corresponding to very high speeds, efficiencies approaching unity are possible. The formula does not give a solution when the loss of head exceeds the dynamic head of the free stream, and we know that with trailing edge flaps a pressure 50 per cent. in excess of this can be obtained. The significance is probably that streamline flow is only possible when the internal pressure drop is less than the dynamic head, and any pressure in excess of this will be costly in drag.



$\frac{h}{H}$	0·2	0·4	0·6	0·8
η	0·95	0·87	0·82	0·73

FIG. 8.

The size of the exit for a given engine resistance and forward speed is obtained from the Bernoulli equation :—

$$p_0+\tfrac{1}{2}\rho V^2=h+p_1+\tfrac{1}{2}\rho V_1{}^2$$

and if $V_1=Q/A$, where A is the exit area,

$$A^2=\{H-(p_1-p_0)-h\}/\tfrac{1}{2}\rho Q^2.$$

The term p_1-p_0 is the increase in static pressure at exit over that at infinity. It may be taken to be determined by the external field, and it will generally be negligible.

If the issuing stream is being discharged near the front of the body, it is obvious that it should be discharged smoothly in the direction of the passing stream, to avoid spoiling the flow.*

It will be noted that the size of entry does not enter into the equations.

* Actually the drag depends only on the mass and total head at exit for $D=\rho Q(V-V_2)$ and $V_2=\sqrt{\{2(H-h)/\rho\}}$.

Entry Loss

It has been pointed out that the essential power for cooling drag is small and it has been shown that the necessary flow can be induced at high speeds with high efficiency. We have, however, assumed that the air can be slowed without loss of energy or rather that the term " h," used for the engine loss, includes all losses in the ducts between entry and exit; if there is any considerable loss of head at entry and in slowing down the air, the actual efficiency may be much below that stated.

It is possible to slow the air without loss if it can be kept away from any surface, as happens with an ordinary pitot tube. If, however, it is being slowed while passing over a surface, as soon as the boundary layer exceeds a certain thickness breakaway occurs, with a considerable loss of head. If the breakaway depends on the kinematic viscosity (ν) velocity gradient and boundary layer thickness, the non-dimensional expression must be $(\delta^2/\nu)\ (dV/ds)$, where δ is the boundary layer thickness and s is the distance back from the nose, and this must not exceed the critical numerical value. It is obvious that the air entry must be kept well forward where δ is small and if for some reason the entry must be back, the air speed should be very gradually reduced, or some means taken to get rid of the thick boundary layer.

Tests in the 24ft. Wind Tunnel

The tunnel was formally opened in April, and apart from preliminary calibration tests it has been working continuously on cooling problems. The first problem was to determine the real magnitude of the engine and cooling drag of existing engines, a point on which there was considerable uncertainty, and the second was to see how far these items could be reduced by the application of the principles just considered.

Two installations were chosen for our preliminary investigations:—

(1) The Gauntlet fitted with a radial air-cooled Mercury VIS engine having a simple ring cowl, and
(2) The Bulldog fitted with a Rapier air-cooled in-line engine.

The Gauntlet is typical of the best modern practice of a fixed cowl unbaffled installation, while the Rapier Bulldog, on the other hand, is a completely baffled installation which lends itself to experiments on controlled cooling flow.

In both series of tests, measurements were made to determine:—

(a) The quantity of air passing through the cowl.
(b) The cooling drag.

This was deduced by difference from measurements of the drag of the aircraft with engine, and the drag of the aircraft with the engine removed and replaced by a well shaped nose fairing. The drag difference found by these tests was taken to be the cooling drag of the installation. The measurements, of course, could only be made without slipstream.

(c) The drag loss inside the cowl.

This was obtained from measurements of the total head and velocity of the air leaving the cowl. The method is analogous to the determination of the drag of a wing from the pressure and momentum in the wake. The measurements were made with and without slipstream.

The difference between (b) and (c) gives the spoiling effect on the engine and cowl installation.

I shall describe first the Gauntlet tests. The cowl is shown in Fig. 9. In these tests the total head and velocity over the inlet and outlet areas of the cowl were determined from readings of combined pitot static tubes. Three such tubes were used to explore the cowl entry and four tubes were fixed in the exit. These

tubes were spaced at various angular positions around the cowl and were moved in turn to four positions radially across both the entry and exit of the cowl.

The tests were made with and without airscrew running, and in the tests without airscrew the airscrew was removed and a small gear case fairing was fitted.

The tests with airscrew were made at a series of speeds and at engine revolutions corresponding to level flight and climb advances respectively.

In addition to the flow measurements the drag of the Gauntlet was measured and the cooling drag was determined by repeating the drag experiments with the engine and cowl replaced by a nose fairing to the fuselage.

The main results are given in the table below. The cooling losses are given in h.p. and as percentages of the engine power.

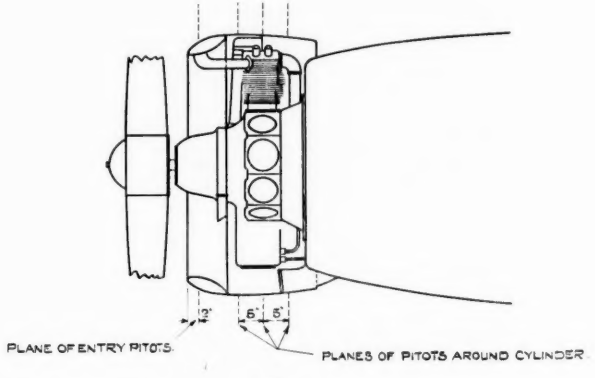


FIG. 9.

Installation of Mercury VI.s engine and cowl on gauntlet.

	Level flight at 15,000ft. at 230 m.p.h.		Climb at 13,000ft. at 139 m.p.h.	
	With airscrew.	No airscrew.	With airscrew.	No airscrew.
Engine b.h.p.	675	—	640	—
Flow through cowl (lbs./sec.) ...	33.2	38.2	20.4	—
Flow through cowl (lbs./sec./h.p.)	0.049	—	0.032	—
H.P. absorbed in cowl deduced from flow measurement ...	34 (5%)	19.5 (3%)	6.5 (1%)	—
Cooling drag from balance readings (lbs. at 100 f.p.s.) ...	—	12.4	—	—
H.P.	—	54 (8%)	—	—

Inspection of the table shows that under level flight conditions:—

1. With no airscrew the cooling drag is 8 per cent. of the b.h.p.; 3 per cent. of the b.h.p. is absorbed in the cowl so the spoiling drag is about 5 per cent.

2. The airscrew increases the power absorbed in the cowl from 3 to 5 per cent. of the engine power and seriously reduces the flow. This is due to the breakaway of the flow behind the boss. Under flight conditions the total cooling drag must thus be at least 10 per cent., *i.e.*, 2 per cent. above that deduced from the tests without airscrew.

3. If the engine is adequately cooled on the climb when the power absorbed is only 1 per cent. of the b.h.p., the flow at top speed must be greatly in excess of what is required. An excess of 50 per cent. is computed.

In any air-cooled engine installation the cowl must provide sufficient cooling air to satisfy the conditions experienced on the climb. These conditions are always more severe than those met with at top and cruising speeds, and consequently the cowl that satisfies the climb conditions invariably permits more cooling air to pass through the cowl than is required to cool the engine adequately at the higher speeds.

We have just seen in the case of the Gauntlet cowl, that a mass flow approximately 50 per cent. in excess of the amount required for cooling the engine was passing through the cowl under level flight conditions. By suitable throttling of the emergent stream from the cowl, therefore, it should be possible to decrease the power losses inside the cowl and also to increase the efficiency of the induction of the flow by a relative increase of the velocity of its wake relative to the aeroplane.

To investigate the possible reduction of drag resulting from the application of this principle, some controlled cowling tests were carried out on the Rapier Bulldog and these tests will now be described.

Tests on Rapier Bulldog

The first series of tests made on the Rapier Bulldog was with a cowl arrangement that had been flown full-scale. These tests were made to establish the cooling drag and also to furnish a basis of cooling flow on which the subsequent controlled cooling experiments could be considered; the flight tests with

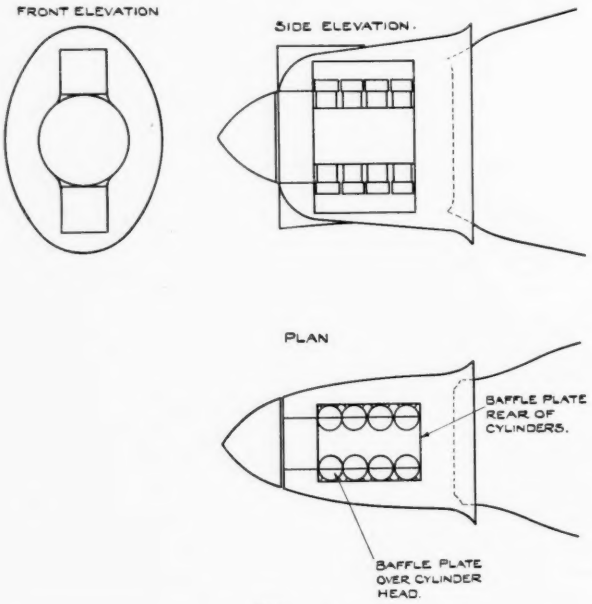


FIG. 10.

Diagrammatic sketch, showing internal baffle system and cowl as originally fitted for cooling tests on Rapier Bulldog.

this particular cowl arrangement having shown that the cooling flow was adequate. The method of tests followed closely on the lines of the tests already outlined in the case of the Gauntlet. Details of the cowl are shown in Fig. 10.

Flight tests had shown that the engine was adequately cooled on the climb at 95 miles per hour and from the flow measurements it was deduced that 0.32 cu. ft. (0.024lb.) of air per second per horse-power was required to cool the engine at maximum power.

The cooling drag at level flight attitude was 12.2lb. at 100 feet per second corresponding to 6.2 per cent. of the b.h.p. at the top level speed of 150 m.p.h. and the flow through the cowl was 28 per cent. in excess of the actual quantity required to cool the engine.

Passing now to the controlled cowling tests, the cowl was redesigned, first by incorporating controlled exits, and secondly by adding fairing pieces to the entries (Fig. 11). The points in the new design are that the flaps allow the exit

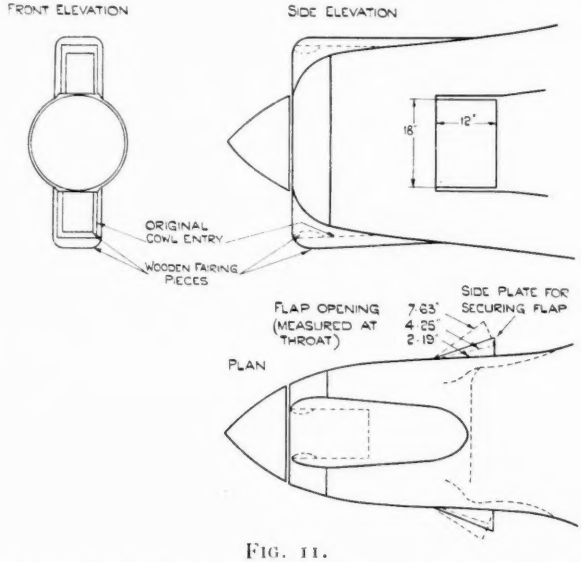


FIG. 11.

Details of faired entry used in conjunction with controlled exit. Cowling tests on Rapier Bulldog.

air to discharge without undue disturbance to the outside flow. The entry has been carefully shaped to prevent breakaway for the flow over the range of forward speed required. Wool tuft exploration was found of great assistance in developing the entry shape. With the flaps set to give adequate cooling the level flight cooling drag is now 3.0lb. at 100 feet per second, *i.e.*, at 1.5 per cent. of the b.h.p. of the engine. The corresponding figure deduced from flow measurements for the power absorbed in the cowl was 2½ per cent., which seems to indicate a negative spoiling drag. The nose fairing used to obtain the zero for the drag tests may not have been perfect, but a considerable portion of the resistance of the aeroplane is due to the body and the projection behind the engine and their drag may have been less in the de-energised air.

The effect of opening the flaps on the flow and drag may be seen from the following table and the large increase in drag when the flaps are opened to large angles will be noted.

TABLE SHOWING COOLING DRAG AND QUANTITY OF AIR PASSING THROUGH THE COWL.

Cowl detail.	Drag due to cooling lb. at 100 ft. per sec. Level attitude.	Drag due to cooling lb. at 100 ft. per sec. Climb attitude.	Quantity of air passing through cowl in cu. ft. at 100 ft. per sec. Level attitude	Quantity of air passing through cowl in cu. ft. at 100 ft. per sec. Climb attitude.
Cowl No. 1 (as flown)	12.2	10.8	72	68
Controlled cooling cowl with faired entry scoops inlet area 0.91ft.—				
Exit area 1.91ft.^{2}	16.4	17.2	69	—
1.06ft.^{2}	4.5	6.7	59	—
0.55ft.^{2}	2.5	4.5	52	—
0.23ft.^{2}	2.4	—	48	—

Tests were made also to determine the drags of the external exhaust and external oil-cooling systems fitted to the Rapier Bulldog. These tests showed that the drag due to the exhaust pipes was about 5lb. at 100 feet per sec. and of the external oil-cooler 1.7lb. at 100 feet per sec. Both these losses should be eliminated on a high speed aircraft.

Reviewing the cost of cooling results for the Rapier Bulldog and Gauntlet installations it appears that at maximum level speed, using fixed cowls, the cooling drag of the Rapier installation is costing about 6 per cent. of the b.h.p. while for the Gauntlet the cost is about 10 per cent. It has been shown from the Rapier that by using a cowl with adjustable exit this loss can be reduced by about 5 per cent.; for the Gauntlet a reduction of about 9 per cent. is estimated. The actual minimum drag cost is a little arbitrary as it depends on the nose shape relative to which the drag differences have been measured, but is clearly very low. The Gauntlet result is interesting in showing that this low cooling drag is possible without the addition of an internal baffling to the cylinders.

Exit Conditions

The conditions to be satisfied at exit are pretty clear apart from the possibility of the " tired " air reacting on the main flow. It is obviously very bad practice to discharge de-energised air at any point where the flow has small stability, *e.g.*, on the upper surface of a wing or above a wing root fillet. Release on the wing lower surface is relatively harmless, but probably discharge at the trailing edge is ideal. Apart from this spoiling there is no mystery about the discharge. The cooling air must have a smooth easy passage to join the outside stream. An engine installation under given power and flight conditions requires to maintain a certain pressure across it for cooling flow. For the Rapier at full power this head appeared to be about 8.3 inches of water. If the flight range extends to sufficiently low speeds we may have to use flaps set to large angles to induce the cooling flow. If, however, the climb speed is high enough so that a pressure difference less than the dynamic head will supply this head there is no need to use high drag flaps and the exit should be designed to give the maximum momentum to the issuing stream.

Recovery of Heat Energy

The increasing dynamic compression which is available as flight speeds increase make it possible to recover energy from the heat added to the cooling flow. The heat is added to the air after compression and gives increased momentum to the discharging stream. The efficiency of conversion is $1-(p_o/p)\,(\gamma-1)/\gamma$ where p is the absolute pressure at which the heat is added and p_o is the static pressure of the outside stream. The value of this, if the full adiabatic rise were obtainable, is 4 per cent. at 300 m.p.h. and it increases as the

square of the forward speed. The cooling power is of the order of half the engine power, and if the exhaust heat be also available at least twice the engine power is available. Mr. Meredith has shown that for a typical radiator in a duct the total drag could be reduced to zero at 300 m.p.h. by making use of the cooling energy or at 140 making use of the cooling and exhaust energy; above these speeds a thrust is obtained. Similar results could be given from an air-cooled installation. Preliminary experiments have confirmed that a reduction in drag approaching the order of that calculated can be obtained.

Concluding Review

I have indicated the lines on which we must proceed to keep down cooling losses as flight speeds increase. The dangers of serious entry losses must be kept in mind.

Oil-coolers can be of the internal type and when provided with a duct so that the cooling air discharges at the trailing edge we have found the drag too small to be measured.

In many cases baffles can be used to reduce cooling losses, but the Gauntlet results I have described, suggest that efficient cooling at low power cost can be obtained without that complication.

Increase of speed provides us with a convenient adiabatic compression and the possibility of using this heat cycle so that our cooling will add to the propulsive instead of to the drag force.

I wish to thank Mr. Jennings and Mr. Perring for their assistance in preparing this paper and to acknowledge my indebtedness to Mr. Meredith for many of the ideas I have mentioned.

Discussion

Professor L. Bairstow (*Fellow*): He congratulated Dr. Douglas upon having put forward the very interesting results of six months' work in the new tunnel at Farnborough. Those who had been associated with the problem for many years, he said, realised that the atmosphere with regard to it had changed enormously during the last six months; at the beginning of that period, no one would have quoted the figures of 10 per cent. loss in the case of the Gauntlet at top speed or 6 or 7 per cent. in the case of the Bulldog, but nowadays those losses were spoken of quite certainly because they were definite measurements.

The problem, of course, was a very old one, and Professor Bairstow recalled that he had come into contact with it as far back as 1917, when rotary engines were in existence and Colonel Hopkinson had wanted to know how to reduce the drag losses of the rotary engines. An experiment was made at Farnborough in which a cowl with varying openings was placed in front of the engine, and a certain amount of experimental data was obtained. Gradually the position had changed; the rotary engines were abandoned, and there had followed a period in which everybody had been afraid of the extremely high drag given to aeroplanes by radial engines, the cylinders of which were standing out in the wind. There were fashions in aeronautics from time to time; but experiments were made from which it was rather concluded that as a competitor with the water-cooled engine the air-cooled engine had not a chance. From a military point of view it was less vulnerable, but from the air transport point of view it was quite out of the question. Gradually, however, the position had changed, and Professor Bairstow believed it would change very much more rapidly in favour of the air-cooled engine as the result of the experiments in the tunnel at Farnborough.

It was a little surprising to find in the paper only a scanty mention of the work of Mr. McKinnon Wood. For many years Mr. McKinnon Wood had been a strong advocate of duct cooling, and, so far as model experiments were con-

cerned, he and his co-workers at Farnborough had made many experiments in which they had measured the loss of head by difference of pressure and had arrived most positively at the conclusion that duct cooling was an advantage. A small sub-committee of the Research Committee had been formed specially to discuss this problem. Always they were up against the difficulty on the model scale of reproducing the cooling conditions and heat conditions that existed in engines on the full-scale in order to make the necessary measurements and check the deductions. Full-scale flying experiments were very expensive.

It was in that atmosphere that the construction of the big tunnel was considered. Dr. Douglas had anticipated that questions might be raised as to why that particular size of tunnel was chosen. In the first place, it was not looked upon as an apparatus for testing a complete aeroplane; it was thought that that could be done in other tunnels. The compressed air tunnel was being considered at the time, so that aerodynamically it was felt that the experimenters would be in a good position to deal with such problems. But the one great advantage of the tunnel chosen was that one could have an actual engine running under flying conditions, at any rate at the lower angles of flying speed range. After quite a considerable discussion the decision was made to have a 24ft. tunnel. Professor Bairstow was not sure that there was any great merit in the dimension of 24ft.—the Americans had a 20ft. tunnel. But, having had six months' experience of the 24ft. tunnel, in which experiments were made by an experienced staff, it could be said that it was already giving a very great return on the outlay. One hoped that it would continue to provide them with information for many years.

Dr. H. C. H. Townend (*Fellow*): Referring to the point made by Dr. Douglas that on the Gauntlet, fitted with a radial engine, a very low cooling drag was possible without the addition of internal baffles, he said that that would appear to mean one of two things—either that it was not necessary to restrict the quantity of air flowing through the engine to a very small quantity, or that if it was, it was not necessary to keep that air in close contact with the cooling fins. These conclusions, it would seem, were somewhat at variance with reports received from America. He asked if Dr. Douglas had any information as to the quantity of air which did in fact flow through a highly baffled engine, and how it compared with the amount that flowed through in the case of the radial engined Gauntlet, in which he had obtained the low cooling drag referred to.

Dr. G. V. Lachmann (*Associate Fellow*): He regarded Dr. Douglas's paper as a very important one and one which married very well with a paper read many years ago before the Society by Professor Melvill Jones, where Professor Jones had shown how performance would be increased by reducing the drag of an aeroplane to pure skin friction. Nowadays, they were on the way to achieving designs of that kind; induced drag had lost its sting at the high flying speeds and interference drag, strut resistance, etc., were things of the past and they were thinking now in terms of skin friction only. The second still remaining drag was the cooling drag, and Dr. Douglas had put forward most exciting prospects in regard to the manner in which the drag could be reduced or even have its sign reversed. Therefore, looking at aircraft design from a higher viewpoint, the two basic problems were to reduce the external drag to skin friction and to reduce the cooling drag to the minimum, or if possible even to regain energy from the exhaust.

Commenting on the point made by Dr. Douglas that the drag of an oil cooler could be reduced to practically nothing if the exit of the duct were arranged on the trailing edge, he said that a practice in America was to arrange the oil cooler inside the cowling and to discharge the air through a gill running round the cowling. He asked if the latter arrangement was very much inferior to the former.

Mr. F. M. Thomas (*Associate Fellow*): He asked whether a check had been made of the effect of the airscrew spinner upon the cooling?

Mr. C. N. H. Lock (*Fellow*): Might not the " shadow " produced by a model as large as the Bristol Fighter in the five-foot tunnel have a considerable effect on the results? He also asked if Dr. Douglas had any further information as to the effects of heating an aerofoil upon the skin friction, as he was not sure whether the result shown was purely theoretical or whether there was any experimental evidence existing on the subject.

Mr. O. E. Simmonds (*Fellow and Member*): He acknowledged that he owed much to Dr. Douglas, under whose care he had been placed when he had joined the Royal Aircraft Factory some 14 years ago. The chief thing Dr. Douglas had taught him was that all wind tunnel figures should be regarded with grave suspicion; and in those days two models, one of an R.A.F. wing and another of airship shape, were being sent around the world in order to find out what each wind tunnel had to say about them. Presumably, the tests were still flourishing, under the ægis of the League of Nations!

A paragraph of the paper which Mr. Simmonds did not like very much was that in which Dr. Douglas had discussed the reasons for choosing the 24ft. size of tunnel rather than a larger size. It was stated that in order to be able to test full-scale specimens under maximum speed conditions it would be necessary to increase the h.p. of the fan from 2,000 to 100,000. A question which most people were asking, however, was that, assuming the speed limitation of 115 m.p.h. were retained, why should they not have a channel of double the cross-sectional area, perhaps a duplex tunnel, so that when desirable they could get a complete full-scale aeroplane into the jet.

He gathered that so far the tunnel had been used almost exclusively for experiments on cooling. But there were a hundred and one other problems which required full-scale wind channel investigation; and he asked what the staff of the factory were doing to press the Air Ministry into providing the necessary equipment. There were larger tunnels existing both in France and in America, he believed, and it would be a pity if they in this country, having the one tunnel of 24ft. diameter, were to rest on their laurels.

The final figures showing the cooling drag when the exits were baffled and when they were closed were most interesting, and when Dr. Douglas had spoken of a thrust from cooling one was much intrigued. Indeed, Mr. Simmonds was reminded of the wise words of the famous explorer, Nansen, that the difficult was that which required a little time, and that the impossible required a little longer. One fancied that if those who were really going to offer something to the science of aeronautics would stop worrying about the difficult things and would leave those to the lesser fry, but would themselves go frankly for the impossible, a great deal more progress would be made. He congratulated Dr. Douglas upon the interesting information he had put forward in the paper, and upon the fact that he was going for the impossible; those engaged in the manufacture of aircraft and aircraft accessories must express their indebtedness to Dr. Douglas. Mr. Simmonds was of opinion when he was at the factory that the whole of the work carried on there was too academic and too far removed from the practical necessities of the industry; he believed Dr. Douglas was one of the men they had to thank for having changed that attitude, and there were many others, both at the Ministry and at the factory.

Mr. J. S. Buchanan (*Fellow*): What appealed to him even more than the information of the measurement of the cooling drag of engines were the future possibilities which the paper suggested. He re-echoed Dr. Lachmann's remark that the drag of aeroplanes was being reduced or would be reduced to skin friction, and that the drag remaining to be dealt with was that produced in cooling the engine. The industry was very much indebted to those operating the 24ft. tunnel, for having thrown some light on the possibilities of the future. It was intriguing to think that at some stage they might get something back out of the enormous amount of energy which in the past had passed through the exhaust.

Mr. H. L. Hall (Imperial Airways, Ltd.): He felt sure that the work Dr. Douglas was doing was leading in the direction in which all aeronautical engineers desired to go. Commenting on the desire expressed in some quarters that they should have available a tunnel larger than 24ft. diameter, he said it seemed that with a 24ft. wind tunnel they could explore in the greatest detail the behaviour of small but real aeroplanes, and no doubt they could apply the information obtained to larger types. He had seen the 24ft. tunnel and had heard of larger ones, and wondered whether anyone would have the courage to keep pace in wind tunnel design with aircraft design. They might ask those concerned to make, for example, a wind tunnel which would take the H.P.42, having 130ft. span, and he would be interested to hear Dr. Douglas's estimate of the h.p. that would be required in the operation of such a tunnel. He was not anxious to go for the next to impossible; he sought the tangible, and asked that we should have it quickly.

Mr. H. B. Irving (National Physical Laboratory, *Fellow*): He would like to see more large tunnels available. If he had another large tunnel he would want to use it, not so much for the very important work on performance and cooling drag, and so on, but for finding out a lot more about the stall, rolling stability and the flow over the wings at the stall. One might have another tunnel similar to that at the Royal Aircraft Establishment for testing, not the full-scale aeroplanes, but models of about half size. One would then test these half-scale models at a speed of about double the stalling speed of aeroplanes, and in that way one would get for the complete aeroplane the full-scale Reynolds number at the stall; one could not do it for a very big aeroplane, but one could for moderate size of aeroplane. By such means one could find out a great deal about stalling, much more quickly than we were finding out by flying experiments, and much more cheaply.

With regard to Dr. Douglas's remark on the single return tunnel flow as against the double return flow, that the single return tunnel did give a very good distribution, Mr. Irving asked whether there was likely to be less shadow effect in the single return type than in the double return type.

Mr. F. Radcliffe (*Associate Fellow*) (*contributed*): He had read through with the very greatest interest Dr. Douglas's paper on the work of the 24-foot tunnel, and, in particular, he had been interested in Part Two, which related to cooling problems.

An expression is given for the efficiency of the duct system of cooling. He would suggest that if an appendix to the paper could be added, which would amplify the methods of obtaining the expression, students of the paper would find this of very great value.

He would be glad if Dr. Douglas could explain at greater length the formula dealing with the theory of duct design.

In connection with the statement that the size of entry does not enter into the equations, he would be glad if the author could confirm whether the statement has been verified by tests, or not.

Could the author give the effect of baffles and adjustable skirts to Townend rings, as mounted on the Gauntlet aircraft? Does the author think that a gain would be derived from the combined use of these two refinements?

Mr. H. F. Winny (*Associate Fellow*): When referring to the problem of heat dissipation on the Schneider Trophy aircraft, Dr. Douglas suggests a 4 per cent. increase in drag due to a rise in temperature of the surface of 100°C. It would appear from the context that Dr. Douglas is considering only the skin friction, in which case one is surprised at this result, since the drag coefficient is increased about 4 per cent., but the density is decreased about 10 per cent., giving a net decrease in drag of 6 per cent. It may be that Dr. Douglas is considering the flow in greater detail, in which case it would be of interest to know the essentials of his method. For example, the temperature field around a hot body may give rise

to an appreciable drag due to the density and velocity changes in the surrounding air even at moderate velocities. As far as he was aware this problem has not yet been investigated.

Reply to Discussion

In the first place he took the opportunity to express, on behalf of his department, very great indebtedness to Mr. McKinnon Wood for having given a lead in this work. Mr. Glauert was another who had done much to help. He added that when preparing the paper he had felt that he was recording the work of the department and of the various people in it, rather than his own work.

Replying to Dr. Townend, he said the evidence obtained at the Royal Aircraft Establishment was that baffles did reduce the cooling drag; but the real point in the case of the Gauntlet test was that without baffles the cooling drag could be so low that it was not worth the complication of baffles to reduce it further. Actually the Gauntlet had a relatively low cooling flow; there was a very narrow gap at the trailing edge of the ring. If one compared the Gauntlet, which might be called a simple ring installation, with the Rapier type, which was highly baffled, one found that there was not so very much difference between the cooling flows per h.p. As stated in the text, the Gauntlet required 0.032lb. of air per second per b.h.p., whereas for the baffled Rapier engine the corresponding figure was 0.024lb.

The problem raised by Dr. Lachmann, as to whether it was better to discharge the tired air from an oil cooler at the trailing edge, where it was a little inconvenient, or to discharge it at the gill, had been dealt with generally in the paper. If one had a nacelle with a rather short tail fairing it was definitely dangerous to do so; one was liable to get a very disproportionate increase of drag through discharging at the gills. If, on the other hand, one were dealing with a body having a long fairing, he believed it would make relatively little difference. The general consideration to be kept in mind was that it was always bad policy to discharge tired air at any point where the flow was critical.

The effect of airscrew spinner upon cooling, to which Mr. Thomas had referred, was a matter on which an investigation was proceeding.

Replying to Mr. Lock's question as to the shadow of the Bristol Fighter in the 5ft. tunnel tests, he said the full results of those tests were given in R. & M. No. 1348 by Mr. Perring. There was a definite shadow, but it did not appear to be sufficiently serious to have much effect upon the results.

As to the effect of the heating of an aerofoil upon surface friction, Dr. Douglas said there was no direct experimental evidence obtained from tests on an aerofoil. The results given in the paper were deduced from measurements of the rise of resistance to flow in heated pipes and there seemed little doubt that in the case of a wing the result was as stated.

Mr. Simmonds question concerning the size of the tunnel has been in part answered by Professor Bairstow and Mr. Hall. The tunnel dealt with in the paper was very convenient for the class of work for which it was being used, and there seemed to be any amount of work of that nature that could be done in it. For a bigger tunnel it would be essential to build balances having a greater capacity; the accuracy would be lower, and generally the time of testing would be increased. If it were required to examine the drag of an aeroplane in the tunnel it would be difficult to secure sufficient accuracy using the whole aeroplane, whereas if one placed in the jet the portion in which one was particularly interested, measurements of high accuracy could be obtained.

A reminder had been given by Mr. Irving that for the study of wing stalling the tunnel was so designed that one could test a half-scale model in it and get any derivatives required at the correct Reynolds number.

In reply to Mr. Irving's reference to the effect of shadow, Dr. Douglas agreed that the shadow effect should be less important in a double return tunnel.

Mr. Radcliffe has asked for some further explanation as to the drag which occurs when flaps are used to produce a large pressure difference across the engine. The point is that the flaps in producing suction cause an eddying wake so there must be considerable excess of drag above what would occur with streamline flow.

As regards entry, experiments show that the entry size can be varied over a wide range without seriously affecting the results.

The R.A.E. tests on baffles and adjustable skirts were confined to the long ring type of cowl.

In reply to Dr. Winny, I should state that no exact solution of the problem of effect of heating a body on its drag has been obtained. Three effects have to be considered: (1) The increase in viscosity, (2) the decrease in density, and (3) the increase in thickness of the boundary layer. The increase in viscosity is fully effective since the viscosity is only important in the laminar sub-layer, which will have the same temperature as the surface, but the decrease in density is a mean effect which is spread through the boundary layer and is less important. The third effect is also small and of opposite sign to the second. The increase in viscosity is therefore the dominant factor and this is the only one which has been allowed for.

The PRESIDENT: He recalled that his recent activities had compelled him to pass through the Mersey Tunnel three or four times a day, and consequently the 24ft. wind tunnel appeared to be quite microscopic. He fully realised the truth of the remark made by Mr. Hall, that workers in the aeronautical field could never really get the size of tunnel that theoretically they would like. But they might have had the 24ft. tunnel, proi[illegible] with advantage, a little earlier, because it was interesting to see that by [illegible]g the purely mechanical problem of air cooling they would have come acro[illegible] interesting aeronautical results. It was rather curious that in the case of bi[illegible]nes on aircraft, air cooling was a thoroughly satisfactory way of getting rid of the heat; yet the air-cooled engine had been so very unpopular in the ordinary motor car. He knew of only one motor car—and it was American—the engine of which was air-cooled, and it was thoroughly satisfactory. Those who motored in London knew perfectly well that the engine of a motor car never ran properly until one had arrived at one's destination. It was interesting that the Royal Aircraft Establishment had proved that the smell of a motor bus was pushing it along! That was a very stimulating thought!

But he was very pleased that Dr. Douglas had presented his paper, for he had set many people thinking. There were many things he would be able to do in the 24ft. tunnel, and about which one hoped he would address the Society in the future. The President proposed a hearty vote of thanks to him for his work and for the clear manner in which he had expressed the results.

The vote of thanks was carried with enthusiasm, and the meeting closed.

ABSTRACTS AND NOTICES
FROM THE
SCIENTIFIC AND TECHNICAL PRESS

PART I.—PHYSICS AND ENGINEERING SCIENCE

Issued by the
Directorates of Scientific Research and Technical Development, Air Ministry
(*Prepared by R.T.P.*)

No. 36. DECEMBER, 1935

Aircraft Design, Performance, etc.

Aerodynamical Research and Test of Fairchild Amphibian. (A. A. Gassner, Aero Digest, Vol. 26, No. 5, May, 1935, pp. 30-33.) (5.10/30698 U.S.A.)

Sketches show the general arrangement and lines of models tested.

Six nacelle arrangements are shown in detail.

Aerodynamical characteristics are given graphically in six diagrams. A second article describes the full size aircraft.

The wing floats and land carriage are retractable.

Application of Statistical Methods to Structural Strength of Aeroplanes. (H. G. Kussner, L.F.F., Vol. 12, No. 2, 16/5/35, pp. 57-61.) (5.15/30699 Germany.)

The number of machines built in series to the same drawings is too small for statistical analysis.

The author takes the number of hours flown as the axis of abscissæ and the stresses at various times as ordinates.

On this basis the application of elementary statistical methods yields figures of the expectation of life of an aeroplane of a given type.

It is made clear that the expected life of a wing is much decreased with increased flying speed.

Correlations between independent causes of failure yield contours or iso-curves of which two illustrated examples are given.

Two references.

Study of Wing and Body Filleting by Smoke Filament. (J. Valensi, L'Aeron., No. 194, July, 1935, pp. 179-182.) (5.10/30700 France.)

Dimensions of the models are given. Six photographs show the improved flow obtained by filleting. Polar curves show corresponding improvements in the characteristics of the model.

The Efficiency of Wing Sections at Very High Air Speeds. (N. W. Akimoff, L'Aeron., No. 194, July, 1935, pp. 182-184.) (5.20/30701 France.)

This article is a short review of the following publications:—

Gasdynamik, by Busemann.
Raketenflugtechnik, by E. Sanger.
Flugelprofile bei Uberschallgeswindigkeit, by Busemann and Walchner (Göttingen).
R. & M. 1467, by G. I. Taylor.
N.A.C.A. Report 255, by Briggs and Dryden.

Lift/drag values for normal aerofoils diminish rapidly from 18/1 to 2/1 as the velocity of sound is approached and exceeded. The variation with incidence becomes less marked and the maximum L/D is shifted to larger angles of incidence. Thin sharp-nosed sections are better than conventional aerofoils and the latter give a better L/D value if reversed, *i.e.*, trailing edge facing the wind.

(See also "Aerodynamic Lift at Supersonic Velocities," A. Busemann, L.F.F., Vol. 12, No. 6, 3/10/35, pp. 210-220.)

Method of Determining Distribution of Lift Along the Span. (A. Lippisch, Luftfahrt Forschung, Vol. 12, No. 3, 17th June, 1935, pp. 89-106.) (5.20/30702 Germany.)

This paper is of importance to designers.

A brief summary is given, in qualitative terms, of the effect of wing shape, distribution of incidence, recesses (cut out portions), etc., on lift distribution and structural stresses.

The usual theory is applied and the lift distribution is expressed by an integral equation, which is reduced by expressing the lift distribution as a Fourier series. The coefficients in the expansions are obtained as integrals, and it is shown that the terms in the series beyond the third become small, and that neglecting these gives an approximation within 3 per cent. in many cases.

Further approximations are discussed and approximate expressions are obtained.

A numerical example is worked out, the lengthy computations are tabulated and graphical methods of obtaining approximate values are given.

Rolling and yawing coefficients for given moment of the central surface are computed by the same methods and comparison of Lotz's results with the author's first approximation show satisfactory agreement.

Four references.

Airscrews

The Motor Ship "Deutschland." (W.R.H., Vol. 16, No. 12, 15/6/35, pp. 194-199.) (5.65/30703 Germany.)

The vessel is interesting on account of its Voith-Schneider marine blade drive in which the feathering blades are of aerofoil section and project vertically downwards from the horizontal driving disc which is flush with the ship's bottom.

Three references.

Voith-Schneider Marine Screw. (Dr.-Ing. Völker, W.R.H., Vol. 16, No. 15, 1/8/35, pp. 251-253.) (5.65/30704 Germany.)

Two photographs show a full-scale vessel at speed in a seaway and the stern and screw on the slipway. Three further photographs show a model installation in the air for inspection, in the tank with self-driving equipment, and an underwater photograph shows the general flow over the screw in action.

Three diagrams of ships' lines are reproduced giving successive changes in performance.

The search for the best shape of overhung counter and best position of screw has led to substantial improvements in performance. (Possible application to airships is worth consideration.)

Calculation of the Three Lowest Bending Frequencies of Rotating Airscrews. (L.F.F., Vol. 12, No. 5, 31/8/35, pp. 155-160.) (5.05/30705 Germany.)

An empirical equation is given for the fundamental frequency in which the angular velocity appears as a parameter.

Ten references.

German Wooden Propeller with Cellulose Sheathing (Schwartz Patents). (R. Sancery, L'Aeronautique, May, 1935, No. 192, pp. 132-136.) (5.052/30706 France.)

The wooden propeller is closely covered with a special fabric and then impregnated with a plastic material derived from cellulose acetate. The material impregnates the wood, the fabric acting as additional anchoring. High surface finish can be obtained and the leading edge can be further strengthened by metal strips embedded in the compound. Propellers of this type do not splinter when pierced by bullets and stand atmospheric conditions better than normal wood propellers. The construction can also be adapted to variable pitch designs. The method of covering the surface treatment is stated to have been successfully employed on the plywood wings of the Heinkel 70 high-speed monoplane.

Propeller Brakes in Multi-Engined Aircraft. (Aero Digest, Vol. 27, No. 2, August, 1935, page 30.) (5.662/30707 U.S.A.)

Developments were initiated by R. B. Quick, Engineering Inspector for the Bureau of Air Commerce. Tests with a four-engined Sikorsky are described. Two photographs and a diagram are reproduced.

Propeller Stresses. (M. M. Munk, Aero Digest, Vol. 26, No. 5, May, 1935, pp. 22-26.) (5.66/30708 U.S.A.)

An elementary descriptive account is given of the stresses in an airscrew, particularly from vibration in resonance. Simple formulæ are given with a correction factor for blade vibration.

Instruments

Investigation of Current Meters. (S. L. Kerr, Trans. A.S.M.E., Vol. 57, No. 6, August, 1935, pp. 295-301.) (6.22/30709 U.S.A.)

Meter readings are compared with discharge, and with the results of exploration of velocity field with a pitot tube. Comparisons are given in numerical tables and curves.

Differential Analysis. (Engineer, Vol. 160, No. 4149, pp. 56-58-to be continued.) (6.10/30710 Great Britain.)

A description is given of an integrating machine installed in the physics department of Manchester University. (Refer Abstract No. 22649, Journal Franklin Inst., Oct., 1931.)

Water Gauging for Low Head Units. (J. M. Mousson, Trans. A.S.M.E., Vol. 57, No. 6, August, 1935, pp. 303-316.) (6.20/30711 U.S.A.)

Water meters which give satisfactory readings in long channels with reasonably steady mean flow give erratic results in short channels with oblique and pulsating flow.

Two meters, differently affected by irregularity of flow, may be used in combination to eliminate errors of this type.

Twelve references.

Flow of Water Measurement. (W. M. White and W. J. Rheingans, Trans. A.S.M.E., Vol. 57, No. 6, August, 1935, pp. 273-280.) (6.20/30712 U.S.A.)

A battery of pitot tubes is connected with manometers mounted on a board.

A photograph of the manometer board records the distribution of velocity indicated by the pitot tubes.

Irregularities in time and space distribution are eliminated.

Photographs and curves are reproduced.

Three references.

The Rotating Sphere Viscometer. (A. Guillet, Comptes Rendus., Vol. 200, No. 18, 29/4/35, pp. 1522-1524.) (6.225/30713 France.)

Discrepancies obtained with this instrument show that the Theory of Stokes is incomplete. (See also Comptes Rendus, p. 442, of 1935.)

The Logarithmic Diagram. (Application to Phenomena in Engine Cylinders, Discussion.) (A. T. Gregory, S.A.E., Jnl., Vol. 36, No. 5, May, 1935, pp. 191-199.) (6.252/30714 U.S.A.)

Four indicator diagrams are reproduced as a logarithmic scale which transforms parabolas of any order into straight lines. An elementary exposition of the thermodynamical relations is given from the diagrams.

In the discussion two possible sources of error in application of the method were given with numerical examples.

Four references.

Effect of Humidity on Hot Wire Measurements. (N. Paeschke, Phys. Zeit., Vol. 36, No. 16, 15/8/35, pp. 564-565.) (6.40/30715 Germany.)

Details of the hot wire apparatus are given and results of measurements at 82 and 32 per cent. humidity are tabulated graphically.

A systematic difference of the order of 10 per cent. is shown.

Two references.

Pitot Tube Practice. (E. S. Cule, Trans. A.S.M.E., Vol. 57, No. 6, August, 1935, pp. 281-294.) (6.40/30716 U.S.A.)

An account is given of the development of the pitot and venturi tubes and manometers. Calibrations are given for velocity angle and length of projecting tubes.

A special form of pitot head for a wide range of incidence is shown in dimensional sketches.

The pressure head characteristic is nearly constant for axial flow over a wide range of velocities. For a range of incidence, $\pm 5^{\circ}$, an approximation to the cosine curve is obtained.

Training and experience are necessary in taking measurements.

Fourteen references.

Exhaust Operated Venturi. (Flight, Vol. 28, No. 1397, 3/10/35, p. 367.) (6.52/30717 Great Britain.)

A sketch shows the venturi tube placed in an engine exhaust pipe. The pressure difference was used to drive a gyroscope controlling a turn indicator. The venturi tube was of heat resisting material and after a test no accumulation of soot was observed.

Instrument for Measuring Total Pressure, with Small Sensitivity to Obliqueness in the Stream. (G. Kiel, L.F.F., Vol. 12, No. 2, 16/5/35, pp. 75-79. D.V.L. Report 35/03.) (6.40/30718 Germany.)

The instrument is of the venturi type, the pressure head being placed axially.

Sections of various tubes are shown with their points of greatest internal constriction at different axial positions.

Characteristic curves of variation of indicated pressure with inclination of the axis to the stream are shown graphically.

The final arrangement selected maintains the indication up to an inclination of 40° and shows drops of $\frac{1}{2}$ per cent. at 50°, 7 per cent. at 55°, and 40 per cent. at 60°.

Photographs and sketches show the observed streamline, the dimensions of the instrument, and methods of mounting on a wing and trailing behind an aeroplane. (Translated in N.A.C.A. Tech. Memo. No. 775.)

Three references.

Instrument Panel Layout. (Aero Digest, Vol. 27, No. 2, August, 1935, pp. 40-42.) (6.90/30719 U.S.A.)

Descriptions are given of seven instrument boards and illustrated by ten photographs.

Aircraft Flight

Contribution to Theory of Slotted Wings. (F. Weinig, L.F.F., Vol. 12, No. 5, 31/8/35, pp. 149-154. D.V.L. Report No. 35/10.) (7.72/30720 Germany.)

Below stalling incidence of the unslotted profile, the slotted profile at equal incidence shows a decrease in the lift coefficient. In this range the flow is substantially potential flow, and the reduction of the lift can be accounted for by hydrodynamical theory.

The usual Joukowsky transformation is applied to the unslotted wing, the slots are then taken into account. The potential difference at the two ends of the slot as calculated for the unslotted wing sets up a flow which is estimated by drawing a network of streamlines and iso-potentials.

Each partial flow reduces the circulation round the part of the wing downstream from the slot.

Examples are worked out for the unslotted wing and for 15 combinations of slots, and numerical values are given in tables and graphically, showing comparative lift characteristics.

(Full translation in hand.)

Wing Brake Flaps. (W. Pleines, Aircraft Eng., Vol. 7, No. 79, Sept., 1935, pp. 213-219.) (7.72/30721 Great Britain.)

An abridged translation of article in Luftwissen, Nos. 3 and 5, 1935, pp. 58 and 63 and 121-131.

Seaplane Take-off Characteristics. (A. O. Mattocks, Flight, Vol. 28, No. 1396, 26/9/35. Suppt., The Aircraft Engineer, pp. 2021.) (7.3/30722 Great Britain.)

Experimental curves of thrust and resistance are integrated graphically and applied to a numerical example.

Mechanics of Longitudinal Oscillations of Aircraft. (A. Proell, Z.A.M.M., Vol. 15, No. 4, July, 1935, pp. 233-237.) (7.2/30723 Germany.)

Lanchester's simplified theory of long pitching motion is extended. The comparative results are shown graphically.

Six references.

Investigation of the Accelerated Longitudinal Motion of an Aeroplane. (R. Schwarn, L.F.F., Vol. 12, No. 2, 16/5/35, pp. 62-69.) (7.2/30724 Germany.)

Treatment is confined to motion in the plane of symmetry.

The equations of motion are formed as for discussion of stability, empirical functions are substituted for coefficient of lift and moment and their derivations and the aeroplane velocity is eliminated. This leaves two equations which connect incidence with time.

The variables are shown graphically as discrete experimental values with continuous curves representing the empirical expressions employed.

The motions of a Curtis JN4H in a loop are calculated and compared graphically with a loop calculated by Banister and an American report. The author states that the comparison is satisfactory.

Eighteen references.

Engines, Thermodynamics

The Experimental Determination and Theoretical Calculation of Flame Temperature and Explosion Pressures. (W. T. David, Phil. Mag., Vol. 20, No. 131, July, 1935, pp. 65-68.) (8.13/30725 Great Britain.)

The sodium line reversal method of determining flame temperature is held to be in error, since it gives results which are neither in agreement with theory nor do they agree with other experimented methods.

Discussion on C. C. Minters' Paper on Flame and Pressure Development in Gasoline Engines. (A. Taub and others, S.A.E. Jnl., Vol. 36, No. 4, April, 1935, pp. 159-164.) (8.13/30726 U.S.A.)

On the assumption that the flame spreads from the plug in the form of a sphere, a relation is deduced between the rate of increase of flame volume and the rate of increase of flame travel. The necessary data for this are obtained from a plaster cast of the combustion chamber under consideration. A standard of reference is obtained by anaylsis of a combustion chamber known to be " smooth."

Extension of Nuclear Inflammation Theory to Injection Engines. (M. Serrings, Comptes Rendus., Vol. 200, No. 16, 15/4/35, pp. 1376-1378.) (8.13/30727 France.)

In the injection engine, the combustion may be initiated by detonation and there may be several subsequent detonations before combustion is complete. The process thus differs radically from that of the carburettor engine where detonation, if it occurs at all, is confined to the end of the combustion period. (See Comptes Rendus, Vol. 198, pp. 1385 and 1574.)

Black smoke in the exhaust is evidence of thermal decomposition of the fuel (insufficiently diluted with air) by the action of the detonating wave.

One reference.

Flame Temperatures Vary with Knock and Combustion Chamber Position. (G. M. Rassweiler and L. Withrow, S.A.E. Jnl., Vol. 36, No. 4, April, 1935, pp. 125-136 and 146.) (8.13/30728 U.S.A.)

The author used the sodium line reversal method for measuring the " average " gas temperature in an engine, for various parts of the stroke. By fitting three pairs of windows, the temperature of different zones in the cylinder can be compared. One of these zones contained the sparking plug, whilst the other two passed through the centre of the combustion space and near the end

wall, respectively. The optical path is normal to the general direction of flame travel in every case.

For the occurrence of " self reversal," it is concluded that the gas temperature in any one zone at a given instant may be far from uniform. Assuming, however, that the recorded temperatures represent a mean value, the experiments indicate considerable temperature difference between the various zones at the same crank angle. The temperature in the zone containing the spark plug may exceed that near the cylinder wall by over 300°C., the difference being specially marked when knocking takes place. During expansion, the " knocking " explosion is considerably cooler for all three zones, the difference being most marked for the central zone (drop of 160°C. at 80° A.T.D.C.).

The gas temperature curves under knocking and normal conditions cross generally at between 20° and 40° A.T.D.C.

In the comments following the paper, the validity of the method of estimating temperature by line reversal as well as the theory of excitation lag are discussed.

A bibliography of 50 references is attached.

Engines—Design and Performance

Anti-Torque Airscrew Drive. (Sci. Amer., Vol. 153, No. 3, September, 1935, p. 146.) (8.20/30729 U.S.A.)

A photograph shows a rotary engine, turning in one direction and carrying a two-bladed airscrew mounted on the housing. A second two-bladed airscrew is driven by the crankshaft in the opposite direction.

(A return to the Siemens engine of 1917.)

No technical details are given.

The Wolseley " Scorpio." (Flight, Vol. 28, No. 1386, 18/7/35, pp. Supplement b-d.) (8.20/30730 Great Britain.)

A descriptive account is illustrated with photographs, sketches and a sectional drawing.

Report on Experiments Carried Out in the High Altitude Test Plant of Messrs. Isotta Fraschini on Engine " Asso 750 " with the Object of Determining a New Formula for Reducing Power Output to Standard Air Conditions. (Communicated by the Italian Air Ministry, L'Aerotecnica, Vol. 15, No. 5, May, 1935, pp. 456-482.) (8.23/30731 Italy.)

The experiments were carried out at a series of absolute intake pressures ranging from 350 m/m. to 760 m/m. absolute. At each pressure the intake temperature was varied between -20°C. and -15°C. The effect of engine speed was also investigated over the range 1,500-1,900 r.p.m.

1. If the exhaust pressure = intake pressure, the b.h.p. of the engine was related to the intake pressure and temperature according to the following equation :—

$$W_z/W_o = (p_z - 60)(617 - t_z)/(p_o - 60)(617 - t_o)$$

W_z = b.h.p. at absolute pressure p_z (m/m. of mercury).
t_z = temperature °C. at p_z.
W_o and t_o corresponding value under standard conditions (same r.p.m. as W_z).

(The above equation represents the mean relationship over the speed range.)

The formula differs appreciably from that given in N.A.C.A. No. 44, *i.e.*,

$$W_z/W_o = (p_z)(529 + t_o)/(p_o)(529 + t_z).$$

2. The effect of exhaust back pressure was investigated at a series of intake pressures. The results are given by the following equation:—

$$W_{zz}/W_{z0} = .802\,(p_z - 94)/\{[(p_z - p_0)/5.04] - 74\}$$

where W_{zz} = b.h.p. at inlet pressure p_z and back pressure p_z.
W_{z0} = b.h.p. at inlet pressure p_z and back pressure p_0.
p_z and p_0 measured in m/m. of mercury.

3. The effect of the exhaust being at a less pressure than the inlet was next investigated. This corresponds to the case of supercharging at altitude by means of a gear driven blower. In these experiments the intake pressure was kept constant (749 m/m.). The gain in b.h.p. under these conditions was given by

$$\text{gain} = 0.210\,\Delta p \text{ h.p.}$$

where Δp = depression on exhaust side in m/m. of Hg.

Similar experiments are in hand with Fiat plant using a different engine.

N.B.—New temperature factor is 2 per cent. less for $t_2 = 20°C$. than those given by N.A.C.A. 44.

New pressure factor is 2 per cent. less for $p_2 = 400$ m/m. than those given by N.A.C.A. 44.

Winter Operation of Aero Engines. (A. Ferrier, S.A.E. Jnl., Vol. 36, No. 4, April, 1935, pp. 137-146.) (8.23/30732 U.S.A.)

Types of shelter for engine warming in use in Canada are described. Difficulties are reduced considerably by using an oil of low viscosity for lubrication. This seems to have no deleterious effect apart from an increased oil consumption. An oil with a Saybolt viscosity of 63 sec. (at 212°F.) will not require preheating for air temperature exceeding −20°F. Starting up then becomes mainly a question of fuel characteristics and these may entail heating of engine induction system.

Supercharger for Petrol Engines. (Engineering, Vol. 140, No. 3634, 6/9/35, pp. 247-248.) (8.235/30733 Great Britain.)

A photograph and two sectional sketches show the general arrangement of the (Roots type) blower. A photograph shows details of case and rotors.

Two characteristic curves of performance show pressure and volumetric ratio against rotor speed.

The blower may be reversed and used as a vacuum pump.

Diesel Engines in Canadian Commercial Vehicles. (L. Witteck, S.A.E. Jnl., Vol. 37, No. 3, Sept., 1935, pp. 13-20.) (8.25/30734 U.S.A.)

A descriptive account is given of various types of C.I. engines employed in Canada.

Weights and fuel consumptions are stated and photographs show engines and vehicles.

Some performance characteristics are given graphically.

Mercedes Benz 12-Cylinder 700 h.p. Injection Engine (Type O.F.2). (Flugsport, Vol. 27, No. 21, 16/10/35, pp. 475-478.) (8.25/30735 Germany.)

This 12-cylinder V engine employs two stages ignition and has the following leading characteristics:—

Bore, 165 m/m.		
Stroke, 210 m/m.		
Compression pressure	40	atmospheres.
Explosion pressure	60	,,
Fuel injection pressure	95	,,
M.E.P.	7.15	,,

(*a*) Cruising output ... ... 720 h.p. at 1,720 r.p.m.
(*b*) Max. output (short period) ... 800 h.p. at 1,790 r.p.m.
Consumption (*a*) 180 gm./b.h.p. hour ... ... Fuel.
9 gm./b.h.p. hour ... ... Oil (lubricating).
(*b*) 185 gm./b.h.p. hour ... ... Fuel.
10 gm./b.h.p. hour ... ... Oil.

Weight of engine complete with reduction gear, air starter, air bottle, electric generator, battery and propeller hub, 1,033 kg.

Two-Stroke Ship's Diesel Engine, 5,500 h.p. (G. Eichelberg, Z.V.D.I., Vol. 79, No. 5, 2/2/35, pp. 130-132.) (8.252/30736 Germany.)

The fuel injection pipe line is made intentionally long so that sufficient lag is obtained to enable the use of an injection cam which is symmetrical with regard to T.D.C. The engine can therefore be reversed in four seconds without having to touch the injection timing. The scavenging air is supplied by a piston compressor fitted with copper piston rings.

High Speed C.I. Engine Performance. (E. A. Whitney, S.A.E. Jnl., Vol. 37, No. 3, Sept., 1935, pp. 328-341.) (8.26/30737 U.S.A.)

A photograph shows a single cylinder laboratory installation.

Three principal types of combustion chamber are described and illustrated by sketches indicating type of air flow.

Thirteen graphs show characteristic curves of explosion pressure, mean effective pressure and fuel consumption, as functions of clearances, valve passage diameter, quality of fuel, boost, scavenging, temperature of cooling medium, etc.

The figures are also tabulated.

Supercharging Diesel Engines for Ship Propulsion. (W. Pflaum, W.R.H., Vol. 16, No. 12, 15/6/35, pp. 206-210.) (8.275/30738 Germany.)

Three methods of supercharging four-stroke Diesel engines are feasible:—

(*a*) Gear driven rotary blower.
(*b*) Exhaust driven centrifugal fan.
(*c*) Utilisation of underside of power piston.

For large power units of the order of 4,000 h.p. run at low speeds (approx. 100 r.p.m.) method (*c*) is the simplest and has received considerable application of late. An increase of 60 per cent. in h.p. is possible for an increase of approximately 3 per cent. in the weight of the engine plant.

The exhaust driven supercharge is most easily applied to engines of large power output (over 1,000 h.p.), although a few smaller units are also illustrated.

The gear driven rotary blower practically covers the range below 2,000 h.p.

As regards fuel economy, it is difficult to get accurate data. Theoretically the exhaust driven job should be the most efficient since the waste heat is utilised. In practice, provided the mechanical blower is reasonably efficient, there appears to exist but little difference in the specific fuel consumption of engines supercharged according to the three methods described.

Six references.

Increased Performance of Four-Stroke Diesel Engines by Means of Scavenging and Supercharging. (A. Schütte, W.R.H., Vol. 16, Nos. 9 and 13, 1/5/35 and 1/7/35, p. 131 and pp. 221-224.) (8.275/30739 Germany.)

The weight of air in the cylinder at the beginning of compression is calculated on certain simplifying assumptions for various degrees of supercharge and scavenge. By taking into account the heat exchange of the air, the charge weight departs slightly from a linear relationship with degree of supercharge, the difference becoming specially marked at low degrees of supercharge.

According to the author, a supercharging pressure of 4,000 mm. of water produces an increase of indicated h.p. of approximately 45 per cent. together with a normal amount of scavenge.

When supercharging it is generally impossible to prevent some temperature rise of those portions of the engine mechanism which are exposed to the combustion. For small degrees of supercharge, this rise can be controlled by increase of scavenging and thus producing internal cooling. For higher degrees, however, this is not economic. Excessive outside cooling by means of a jacket is to be deprecated since it increases stress in the metal walls. The engine should be designed to run with as high a jacket temperature as possible and stresses are thus automatically reduced. By the exterior use of welded steel wall thicknesses and stresses can be further controlled. It is also advisable to place the cylinder head joint so low that it is overrun by the piston and thus protected from the peak temperatures.

In the case of marine engines using sea water cooling, it is generally impossible to have jacket temperatures exceeding 50°C., as otherwise the danger of deposits arises. In this connection oil cooling is receiving attention.

If all the above factors are borne in mind, it is now generally recognised that supercharging and scavenging provide an efficient means of increasing power output by about 50 per cent. over considerable periods of time without affecting weight and floor space of plant and the specific fuel consumption appreciably.

Five references.

Spark Ignition and Compression Ignition in Aircraft Engines. (K. A. Browne, S.A.E. Jnl., Vol. 37, No. 3, Sept., 1935, pp. 342-348.) (8.28/30740 U.S.A.)

The relative qualities of spark ignition and compression ignition engines are discussed in reference to aircraft requirements.

A specification for a C.I. engine is proposed.

A critical comment follows.

A New Axial Engine. (The Engineer, Vol. 159, No. 4141, 24/5/35, p. 545-547.) (8.292/30741 Great Britain.)

The nine-cylinder axial engine of 7-litre stroke volume is of the swash plate type, and uses spark ignition. In this design the swash plate is mounted on ball bearings on the oblique crank. Under the action of the piston thrust the plate undergoes an oscillation only, whilst the oblique crank rotates continuously. This necessitates ball and socket joints at both ends of the connecting rods (swash plate and piston).

The cylinders are arranged on one side of the swash plate and are provided with a common rotary valve gear.

The engine is intended for omnibus propulsion where its compact shape facilitates installation and increases seating capacity.

From the published performance it appears that a b.m.e.p. of the order of 100 lbs./sq. inch can be dealt with successfully at 2,000 r.p.m., using petrol.

Longer experience will be required to test the mechanical details fully, of which the rotary valve appears the most vulnerable.

Engines—Design and Strength of Components

Vibration Characteristics of Aircraft Engine Crankshafts. (Air Corps Tech. Report No. 3533. A.C.I.C., Vol. 7, No. 664, 23/2/32.) (8.36/30742 U.S.A.)

Torsiographs (using an instrument of the Geiger type developed by the Air Corps) were taken on a number of representative American engines (water-cooled in-line and air-cooled radials).

The engines were operated under a variety of conditions (r.p.m., gearing, coupling, spark setting, fuel). The torsional frequencies were also calculated using the formulæ developed by Timoshenko for constrained and unconstrained shafts. Excellent agreement was obtained with experimental results if the shafts were considered constrained in the case of the in-line engines and unconstrained for the radials. The very much simpler formula proposed by Carter gives slightly lower answers (maximum difference 10 per cent.).

The following general conclusions may be drawn from the report:—

(1) Detonation does not affect amplitude of torsional vibrations.
(2) Pre-ignition does.
(3) Faulty distribution is very detrimental.
(4) Reduction gearing introduces considerable flexibility with a corresponding reduction in resonance periods.
(5) Flexible coupling without sufficient internal damping is detrimental.
(6) Crankshafts of radial engines can generally be designed stiff enough to be free from torsional troubles.

The Bearing Problem in Aero Engine Construction from the Point of View of Materials. (H. Mann and H. Heyer, L.F.F., Vol. 12, No. 5, pp. 168-175.) (8.37/30743 Germany.)

Bearings have to be replaced because they wear or crack. Neither factor is amenable to mathematical treatment. Thus the well known PV factor only gives a measure of the heat generated in dry friction (brake) and the more recent V/P factor only registers minimum friction without indicating the safety factor. On the other hand it is difficult to reproduce working conditions in a testing machine. Recent improvement has been in the direction of materials and design. Bearing materials can be divided into three classes:—Soft, semi-soft and hard. The soft bearing materials (Tn and Pb) are satisfactory, provided no great shock loads have to be dealt with. The bearing metal is cast on to a medium hard bronze shell and recent work has shown that it is an advantage to keep the soft casting as thin as possible (0.3 mm.). Medium hard bearing metals are of the soft bronze type (Pb/Cu) or have a cadmium base. These are cast on steel shells and the bearing metal usually exceeds 1.5 mm. in thickness. Such bearings withstand shock, but require glass hard shafts, which adds considerably to the expense. Hard bearing metals may consist either of hard bronzes (tin base), light alloys or cast iron. Their use is generally restricted to special cases (pistons, valve guides, connecting rod bearings, auxiliary drives).

Thirty-one references.

Engines—Cooling

Directional Distribution of Heat Radiated from Surfaces. (E. Schmidt and E. Eckert, Forschung, Vol. 6, No. 4, July/Aug., 1935, pp. 175-183.) (8.40/30744 Germany.)

Measurements are carried out on metals and non-metals, and the numerical results are shown graphically.

With non-metals the radiation is concentrated near the normal direction. In metals with smooth surfaces, the radiation increases with departure from the normal direction to four times the value along the normal, and falls off abruptly near tangential erections.

There is marked departure from Lambert's cosine relation for smooth surfaces, but for roughened surfaces the agreement is better. Measurements along the normal direction alone are misleading.

Ten references.

Heat Conductivity Distributed Function. (W. S. Kimball, Phil. Mag., Vol. 20, No. 131, July, 1935, pp. 97-128.) (8.40/30745 Great Britain.)

The molecular theory of viscosity and heat conduction is discussed in terms of Newtonian mechanics and a solution is obtained of Boltzmann's equation which meets the requirements of the kinetic theory and satisfies the conditions of conservation of energy, equality of action and reaction, equilibrium of torques, equipartition of energies and persistence of velocities.

The ratio of heat conductivity to viscosity is smaller than the value given by Chapman and Enskog, and an experimental error arising from leakage in heat conductivity measurements is suggested as the cause of the discrepancy.

Five references.

Dimensions of Radiators. (W. Worth, Aviation, Vol. 34, No. 8, August, 1935, pp. 19-21.) (8.44/30746 U.S.A.)

Experiments at Wright Field on airflow controlled by cowling led to the design of radiators with increased surface and reduced resistance.

Diagrammatic sketches show the relative areas of cowled and uncowled radiators.

Numerical values are given and characteristic curves show the reduction in power dissipated.

Heat Transmission during Evaporation of Fluids at Vertical and Horizontal Surfaces. (M. Jakob and W. Linke, Phys. Zeit., Vol. 36, No. 8, 15/4/35, pp. 267-280.) (8.464/30747 Germany.)

The surface is electrically heated and immersed in a liquid bath, the container being surrounded by a second bath of the same liquid which is heated independently; cooling losses are thus reduced to a very small amount. The surface temperature distribution of the heater and that of the liquid are recorded by a series of thermo couples. It is thus possible to calculate the heat transfer coefficient α over a range of thermal loadings (K cal/M^2H transferred from heater to liquid). For ordinary convection α is of the order of 500 K cal/M^2H °C. for water and 150 for C Cl_4.

Engines—Lubricants

Experiments on the Spreading of Castor Oil and its Constituents on the Surface of Water. (C. Bouchet and P. Lamarche, Pubs. Sci. et Tech. No. 51, 1934.) (8.54/30748 France.)

The Oxidation of Mineral Oils at Moderate Temperatures. (M. G. Muller, Comptes Rendus., No. 21, May, 1935, p. 1769.) (8.54/30749 France.)

The oxygen absorption was measured at 100°C., for periods extending to 500 hours.

The amount absorbed varies considerably for different oils and is most marked for super-refined (so-called white) oils. It may amount to 8 litres per 100 c.c. of oil after 300 hours. The absorption of oxygen is accompanied by a liberation of volatile products, viz., water, CO_2, CO, acids, etc. The author has established a satisfactory balance between weight of these products and oxygen absorbed. Only a small percentage of the oxygen enters into the formation of sludge.

Friction and Structure of Mono and Bi-Molecular Layers of Fatty Substances on Metallic Surfaces. (J. Trillat and H. Motz, Comptes Rendus., Vol. 200, No. 15, 8/4/35, pp. 1299-1301.) (8.54/30750 France.)

The fatty substances are dissolved in ether and the solution deposited on a gold film. On evaporation of the solvent extremely thin layers of the solute are exposed to electron diffraction. In addition to the well known gold pattern, the

photographs show regular patterns which indicate that the molecules of the film are attached perpendicularly to the surface. Moreover, the similarity of the pattern structure for the various fatty substances, such as paraffin wax and beeswax, shows that the pattern is principally due to the arrangement of the carbon atoms in the chain and not due to the end radicles. (Diffraction patterns by X-rays, on the other hand, are affected by these radicles.)

It was noted that such films will form spontaneously on metal surfaces exposed to the atmosphere quite apart from the presence of any lubricant. The source of such contamination is not clear.

The Lubrication Requirements of Automotive Worm Gearing. (C. H. Schlesman, S.A.E. Jnl., Vol. 36, No. 4, April, 1935, pp. 147-158.) (8.54/30751 U.S.A.)

No single lubricant possesses all the characteristics desired in worm gear lubrication.

Extreme pressure lubricants are unsatisfactory for this class of work. Under certain conditions such lubricant will oxidise with great rapidity and become solid after a few hundred hours' service.

Engines, Fuels

The Use of Cracked Spirits in the Internal Combustion Engine. (B. Vellinger and G. Radulesco, Comptes Rendus., Vol. 200, No. 22, 27/5/35, pp. 1858-1860.) (8.602/30752 France.)

Cracked spirits are apt to form gum. If the tendency is reduced by refining, the anti-knock value of the fuel suffers. The authors recommend carrying out the cracking process in such a way that a fuel of suitable volatility is obtained without any subsequent refining. The gum formation is kept within suitable limits by the addition of inhibitors such as triphenol and/or products from the destructive distillation of wood.

Engine experiments have justified the authors' conclusions.

Removal of Smoke and Acid Constituents from Flue Gases. (J. L. Pearson, G. Nonhebel and P. H. N. Ulander, J. Inst. Elec. Eng., Vol. 77, No. 463, July, 1935, pp. 1-48.) (8.64/30753 Great Britain.)

Comprehensive data are collected on quantity and distribution in the atmosphere of impurities. The capital and operative costs of cleaning plant are estimated and are held to be small in relation to the abatement of atmospheric pollution.

Eight references.

Carbon Monoxide Danger in Motor Cars. (F. M. Van Deventer, S.A.E. Jnl., Vol. 37, No. 3, Sept., 1935, pp. 322-327.) (8.64/30754 U.S.A.)

Six photographs show examples of exhaust pipe failure leading to poisoning by carbon monoxide.

Recommendations are made for periodical inspection.

Volatility of Gasoline. (J. O. Eisinger and D. P. Barnard, S.A.E. Jnl., Vol. 37, No. 2, August, 1935, pp. 293-300.) (8.64/30755 U.S.A.)

The effect of the temperature volatility characteristics of fuels are discussed, and the advantage of varying these factors with the season of the year is discussed.

Comparison of Various C.F.R. Engines. (A. V. Philippovtch and F. Seeber, Luftfahrt-Forschung, Vol. 12, No. 5, 31/8/35, pp. 161-167.) (8.645/30756 Germany.)

Seven fuels (Nos. 2-8 in table) were tested in eight different engines. The same sub-standard (No. 1 in table) was supplied to all the stations and the octane

number of mixtures of this with benzole were obtained by direct comparison with octane/heptane. The benzol value of fuels 2-8 was next obtained and converted into octane number by using the calibration curve. The results are given in the accompanying table.

The scattering was found to be mainly due to the difference in the calibration curves—*i.e.*, the direct octane number determination of sub-standard mixtures is more difficult than the matching of the fuels against the sub-standard benzol mixture. For this reason the D.V.L. recommend the use of their calibration curve by *all* the stations. This reduces the mean deviation to 0.58 octane number for all the fuels and all the stations, with a maximum deviation of ±2 octane number. This is slightly worse than the published results of the American comparison carried out in 1933 by 19 laboratories. The American results were, however, " selected " before publication whilst the German table gives results of all the stations.

D.V.L. recommend the following :—

(1) The iso-octane and n. heptane should be washed with H_2SO_4 and re-distilled before use.

(2) Great care has to be taken to get the benzol according to specification If possible all the laboratories should be supplied from one common batch.

(3) The same calibration curve should be used by all laboratories for converting benzol values into octane numbers. Direct octane/heptane determination should only be carried out by the station to keep a check on engine constancy.

(4) The same sub-standard should be used by all laboratories. This should link up with the American sub-standard A_3 and C_7.

(5) The heater should be adjusted so that the sub-standard (benzol) mixture is at 300°F., the fuel under test to take up its own temperature.

No.	Name.	% Aromatic unsat.	(Mg.) gum.	Octane No.	Scattering* in O.N.
1	Standard	11%	0.7	52	±2.5
2	Grosny	9%	0.6	54	±3.0
3	2+15% alcohol	—	0.8	68	±1.5
4	2+30% benzol	—	2.2	71	±2.2
5	Coal tar petrol	—	26	72	±2.4
6	B.P. aero spirit	11%	0.6	72	±1.8
7	Aral	44%	4.7	79	±2
8	6-6 c.c./gall. Pb.	11%	0.6	86	±2.5
9	Benzol	—	3.8	—	—

* Each station using its own calibration curve.

Petrol Systems in Aeroplanes of the Acrobatic Class. (L'Aerophile, No. 5, May, 1935, pp. 143-145.) (8.68/30757 France.)

The Stromberg and Zenith carburettors (specially designed for acrobatic flight) are described in detail. The former has a special float chamber fitted with two floats which compensate for change in level. The chamber is vented through an automatic ball valve which prevents loss of fuel when inverted. The fuel delivery holes are placed in such a manner that they are never uncovered and prolonged inverted flight (at full throttle only) is possible if a petrol pump is fitted.

The Zenith carburettor has no float chamber, but is fitted with an inlet valve under diaphragm control. This supplies petrol from the pump to the jets at a constant pressure of 10 gm./cm.^{2}, the size of the delivery jet being controlled by the throttle position. A hand controlled fine adjustment acts as altitude control.

A second valve, also diaphragm controlled, shuts off the fuel in case of a back fire. With this carburettor all types of acrobatic flight are possible at all throttle openings.

Engines—Injection Systems and Pumps

Automatic Power and Mixture Control for Aircraft Engines. (J. E. Beardsley, S.A.E. Jnl., Vol. 37, No. 2, August, 1935, pp. 301-306.) (8.701/30758 U.S.A.)

Details are given of a device for throttling the carburettor intake so as to maintain the density of air entering the choke at the equivalent of 7,000 feet. Characteristic pressure curves are given for the ordinary carburettor and for a controlled pressure carburettor, with the corresponding power/height characteristics.

Photographs and sketches illustrate the details and general assembly of the control device.

Development of Aircraft Fuel Pumps. (E. S. Evens, Aero Digest, Vol. 27, No. 2, August, 1935.) (8.74/30759 U.S.A.)

Pumps of different types are briefly described. A characteristic air compressor of variable pressure and central delivery pressure pump are shown graphically.

Armament

Pressure Developed by Explosives. (P. Bernard, Comptes Rendus., Vol. 200, No. 21, 20/5/35, pp. 1728-1730.) (9.01/30760 France.)

The crusher manometer has been calibrated by a piezo-electric indicator for a series of rapid explosions. The maximum difference was of the order of 17 per cent., the crusher reading low.

Four references.

Comparison between Calculated and Experimental Explosion Pressures of Certain Explosives. (H. Muraour and G. Annis, Comptes Rendus., Vol. 200, No. 23, 3/6/35, pp. 1929-1931.) (9.01/30761 France.)

The explosive consisted of a mixture of trinitrotoluene and ammonium nitrate and was fired by nitrocelulose and nitroglycerine. Maximum pressures were measured by means of a crusher manometer, calibrated piezo-electrically. Using thermodynamic data published by Nernst and Wohl the calculated pressure was in excellent agreement with experimental results (max. difference 3 per cent.).

Sudden Expansion of a Gas. (P. Noaillon, Comptes Rendus., Vol. 201, No. 4, 22/7/35, pp. 258-260.) (9.01/30762 France.)

The propagation of a sudden compression in a gas (shock wave) is well understood, thanks to the labours of Riemann, Hugoniot and others. The phenomenon, being always accompanied by an increase of entropy, is irreversible and thus the propagation of a sudden expansion requires a separate investigation. Reference is made to a two-dimensional solution of the problem by Neyer, reproduced in Geiger and Scheel's Handbook of Physics. The three-dimensional problem presents great difficulties, even if restricted to ideal gases. The author concludes that if the expansion is sufficiently rapid, the gas will occupy only a part of the space offered to it and there is a definite boundary beyond which the bombardment of the molecule does not proceed.

Four references.

Increased Revolver Power. (P. B. Sharpe, Army Ordnance, Vol. 16, No. 91, July/Aug., 1935, pp. 29-31.) (9.11/30763 U.S.A.)

A descriptive technical account is given of the development of the new Smith and Wesson revolver with gas pressures exceeding 20,000lbs. per sq. inch and muzzle velocities exceeding 1,500 feet per second. Test pressures of nearly 50,000lbs. per sq. inch were well stood by the barrel.

Bombardment of Railway Station and Lines. (Chief Naval Engineer Rougerson, Rev. de l'Armee de l'Air, No. 72, July, 1935, pp. 726-736.) (9.3/30764 France.)

A discussion is given of the relative damage inflicted by bombing attacks on stations, rolling stock and electric points in lines. A break in the line where there is no alternative route is much more effective than damage to a large network of a siding where traffic can be switched over to undamaged lines. Hence partial destruction of a great junction may yield negligible results in the holding up of traffic. The destruction of canal locks and especially of canal lines might interrupt traffic for months. Automobile routes are an invaluable complement to the railway systems and are being developed by Germany on the German-French frontier.

Air Power. The Mobile Attack Element. (A. Caldwell, Aero Digest, Vol. 26, No. 5, May, 1935, pp. 11-12.) (9.8/30765 U.S.A.)

Strategical relations of Navy, Army and Air Force in modern war are briefly stated.

Production Design of Ordnance. (J. D. Pedersen, Army Ordnance, Vol. 15, No. 90, May/June, 1935, pp. 347-351.) (9.80/30766 U.S.A.)

In view of the sudden manner in which war usually breaks out, production in peace should be laid out with a view to rapid expansion.

The paper discusses the selection of feasible limits in machine shop practice, the provision of fixtures and gauges, and the preparation and figuring of drawings. A list of proposed tolerances in shell manufacture is essential. Difficulties met with during the last war are described to illustrate the loss of time and material involved in faulty initial layout of the work.

Mechanised Forces. (J. K. Christmas, Capt., U.S.A., Army Ordnance, Vol. 15, No. 90, May/June, 1935, pp. 327-331, and No. 91, July/Aug., 1935.) (9.80/30767 U.S.A.)

A tabular comparison is given, of men, horses, vehicles, tons of supplies, road space, train space, ship tonnage, casualties and replacements on the one hand and mobility and fire power on the other hand.

The paper expands the tabulated material and quotes British, French and German views.

An analysis is given of the problem of supplying a mechanised cavalry brigade. The estimated daily requirements in action are, in round numbers:—Rations, 30 tons; fuel and oil, 190 tons; small arms ammunition, 300 tons; artillery ammunition, 120 tons.

Four photographs of armoured cars are reproduced.

Problems of the Pacific—Causes of War. (W. Prak, U.S. Naval Inst. Proc., Vol. 61, No. 389, July, 1935, pp. 917-927.) (9.80/30768 U.S.A.)

The writer takes a pessimistic view of the situation raised by the pressure of Japanese population.

The naval situation is discussed with reference to Japanese, U.S.A. and British bases for ships and aircraft.

The War Fleet as a Whole. (W.R.H., Vol. 16, No. 12, 15/6/35, pp. 199-203.) (9.80/30769 Germany.)

The relative advantages of speed, armament and protection are discussed in general terms.

The author favours six 13.5in. guns in double or triple turrets in ships of moderate displacement (12,000 tons) and speed (18 knots).

Biplane Tactics Against Fighters. (D. Mackiewiez, Rev. de l'Armee de l'Air, No. 72, July, 1935, pp. 737-762.) (9.80/30770 France.)

Diagrams illustrate tactics, in single and group combats, adapted to field of fire, and in sports, manœuvrability and formation.

Materials, Characteristics, Defects and Treatment

The Components of Steel. (Symposium by K. R. Van Horn and others, Metal Progress, Vol. 28, No. 2, Aug., 1935, pp. 22-27.) (10.10/30771 U.S.A.)

A concise summary is given of the transformation of carbon steels with successive formation of austenite, martensite and pearlite. The account is illustrated by diagrams of molecular lattices, micro-photographs and a phase diagram.

Nomenclature is discussed. A table gives approximate critical temperature of about one hundred carbon and alloy steels.

German Progress in Automobile Castings. (W. A. Geissler, Engineering, Vol. 140, No. 3633, 30/8/35, pp. 234-236.) (10.10/30772 Great Britain.)

The paper, read at the Institute of British Foundrymen, and reproduced in abridged form, gives much German experience in the selection of castings and in melting and casting of piston rings and liners.

Methods of testing are also discussed.

Pitting Due to Rolling Contact. (S. Way, Trans. A.S.M.E., Vol. 2, No. 2, June, 1935, pp. A.49-A.58.) (10.104/30773 U.S.A.)

Pitting is due to the lubricant working its way into small surface cracks and opening them up under hydraulic pressure. Rollers running completely dry do not pit, but oxidise. A high viscosity renders oil penetration difficult and reduces pitting.

Ten references.

Stresses in Overstrained Materials, Report of B.A. Committee. (Engineering, Vol. 140, No. 3635, 13/9/35, pp. 291-2.) (10.104/30774 Great Britain.)

A summary of this report is given and a list of relevant papers published by members of the committee.

Five references.

Electro Magnetic Tests for Work Hardening Steel Wires. (T. F. Wall, The Engineer, Vol. 160, No. 4157, 13/9/35, pp. 261-263.) (10.105/30775 Great Britain.)

Work hardening alters the ordinary magnetic induction characteristics of steel wires slightly and gives no criterion of overloading. Magnetisation characteristics under mechanical load, on the other hand, are modified substantially, linear characteristics become curves, and an easily observed criterion of overload is given. Numerical values are given in tables and curves.

Oscillograms of surges in earthing cables show peaks of load such as produce hardening.

Nine references.

Specifications of Magnetic Qualities. (L. G. A. Sims, Report of B.A. Paper, Engineering, Vol. 140, No. 3635, 13/9/35, pp. 290-291.) (10.105/30776 Great Britain.)

The application of sinosoidal magnetising e.m.f. to an iron circuit produces the well known distorted magnetising current characteristic with sharp peaks at maximum induction.

Instruments which average their values over a cycle give the same time and amplitude means as the ballistic method, but if a D.C. magnetising current is superposed, the mean values no longer agree.

It is considered that special methods should be used for specifying magnetic qualities for operation under the latter condition.

Three references.

Surface Cracking. (H. H. Ashdown, Metal Progress, Vol. 27, No. 5, May, 1935, pp. 29-33.) (10.12/30777 U.S.A.)

Photographs show flawless material cut from a shaft with numerous surface cracks.

The author attributes the cracks to the formation of a surface film by flow of metal and its subsequent rupture by abrupt changes of magnitude and direction of surface load. This may take place in metal initially in irreproachable condition.

New Method of Testing Resistance to Fissuring of Industrial Metals. (P. Brenner, L.F.F., Vol. 12, No. 3, 17/6/35, pp. 107-115. Report 35/05 of the D.V.L.) (10.125/30778 Germany.)

Examples are shown in ten photographs and micro-photographs of fissures which appeared in working materials under influence of stress and corrosion.

A simple apparatus is shown in a sketch, and photographs for subjecting sample strips of metal to a determinate (initial) bending stress under exposure to corroding influences. Examples of corroded lautal, dural and hydronalium strips are shown in photograph, three with characteristic fracture.

Five micro-photographs show the grain of the metal.

A summary of results is given, from which rules as to selection of non-cracking materials and conditions may be drawn.

Four references.

Comparative Tests of Resistance to Corrosion of Eleven Light Alloys Under Natural and Laboratory Conditions. (E. K. O. Schmidt and E. Böschel, L.F.F., Vol. 12, No. 3, 17/6/35, pp. 116-120, D.V.L. 3 Report 35/06.) (10.125/30779 Germany.)

Eleven aluminium alloys in test sheets 1 mm. thick were exposed to natural corrosion by sea water and to artificial corrosion in the laboratory.

The chemical composition and mechanical properties are specified, and the change in the mechanical properties after prolonged exposure (1-24 months) under natural conditions, and briefer exposure (6-180 days) under accelerated laboratory conditions, are tabulated.

Photographs show the external appearance of the specimens after exposure.

The K.S. (sea water) specimens are remarkably free from general corrosion, but show local attack over small areas. With about half the specimens the rate of corrosion, measured by change in mechanical properties, was accelerated as much as 18 times in certain cases. With the remaining specimen no such effect is evident.

Electric Seam Welding Machines. (Engineer, Vol. 160, No. 4154, 23/8/35, pp. 190-192.) (10.14/30780 Great Britain.)

Types of seams are shown in sketches. Five photographs show the external appearance of the welding plant for different types of operation. Consumption of power, and rate of welding are given.

Oscillograph records show the alternating current characteristics during operation.

Development of Welding in Steel Construction. (K. Kloppel, W.R.H., Vol. 15, No. 9, 1/5/35, pp. 137-139.) (10.14/30781 Germany.)

Photographs show fractures in the girders of a swing bridge. Sketches illustrate the method of welding repair adopted.

Welding in German Shipbuilding Yards, No. V. (Six photographs. W.R.H., Vol. 16, No. 9, May, 1935, pp. 140-141.) (10.14/30782 Germany.)

Springing of Automobiles. (N. S. James, H. E. Churchill and F. E. Ullery, S.A.E. Jnl., Vol. 37, No. 3, Sept., 1935, pp. 313-321.) (10.164/30783 U.S.A.)

The methods of analysis of spring suspension problems, given by Professor J. J. Guest at the Institution of Automobile Engineers (1926), are described and applied.

Moments of inertia are determined experimentally with a horizontal compound pendulum, and numerical values are tabulated.

Load displacement curves for front and rear wheels, and for tyres, show typical hysteresis loops.

Continuous Flow Corrosion Tests of Steel Pipes. (H. S. Rawdon and L. J. Waldron, Engineering, Vol. 140, No. 3632, 23/8/35, pp. 208-209.) (10.262/30784 Great Britain.)

Sections of pipe are subjected to continuous circulation of water with known salt or acid content.

Test results (as measured by loss of weight) are shown graphically for different positions in the circulative system. The maximum rate was at the inlet and decreased progressively along the pipe.

Numerical Records of Artificial Drying of Timber. (F. Kollman, Forschung, Vol. 6, No. 4, July/Aug., 1935, pp. 169-174.) (10.400/30785 Germany.)

Expressions are formed for the rate of decrease of moisture under known conditions of temperature and humidity of the surrounding air.

Temperature and humidity characteristics are shown graphically as functions of time of intermittent drying. The methods of predeterminating are approximate.

Twenty references.

Magneto-Optical Properties of Liquids. (M. Schérer, Pubs. Sci. et Tech., No. 50, 1934, pp. 1-91.) (10.403/30786 France.)

Saturated and unsaturated paraffins up to C16, benzenes with one or more side chains, cyclohexanes, etc., were examined optically in a magnetic field, parallel, normal and oblique to a ray of polarised light. The results were correlated with molecular structure.

Accepted theories were confirmed as approximate rules, but the numerical discrepancies are numerous.

In many cases properties of components are approximately additive to give properties of mixtures.

Molecular structure has a fundamental influence on the phenomena.

Electrical Properties of Rubber Compounds. (A. H. Scott, Bur. of Stan. J. Res., Vol. 15, No. 1, July, 1935, pp. 13-24.) (10.408/30787 U.S.A.)

Measurements of capacitance, conductance, dielectric constant and power factor under pressures up to 700 bars (690 atmospheres) are shown in twelve graphical charts.

Twenty-two references.

Fire Resistant Doped Fabric for Aircraft. (G. M. Kline, Bur. Stan. J. Res., Vol. 14, No. 5, May, 1935, pp. 575-587.) (10.60/30788 U.S.A.)

The fabric is first treated with a 3:7 boric acid-borax mixture and subsequently doped with cellulose acetate. This procedure yields a covering which is less inflammable than the normal nitrate.

Bibliography of 75 references.

Testing Apparatus and Methods of Testing

High Speed Wind Channels. (L. Crocco, L'Aerotecnica, Vol. 15, No. 3, March, 1935, pp. 237-275, and No. 7-8, July/Aug., 1935, pp. 735-778.) (11.10/30789 Italy.)

The adiabatic equations of motion of a compressible fluid are formed and the physical relations between velocity, pressure, density and temperature are developed at length.

Applications are made to five types of wind channel, two with closed circuits and three with open circuits. The difference lies in the arrangement of the diffusors and effusors and in the supply of additional air at the exit of the test chamber.

Numerical values calculated from the mathematical theory of the first paper are compared with measurements drawn from a wide variety of sources. The efficiency of diffusors with continuous and impulsive compression, the mass of air, pressure and velocity, power absorbed and Reynolds number attained are shown in functional relation.

Extensive comparisons are made of figures of merit of different types of wind channel. The direct wind channel appears to have the advantage over induced wind channel.

The object of the paper is to establish design data for minimum power consumption for the channel.

(Translation available No. 261.)

Eight references.

Boundary Influence of Wind Channels of Circular Section. (I. Tami and M. Taima, Aer. Res. Inst., Tokyo. Report No. 121, Vol. 10, No. 3, June, 1935.) (11.16/30790 Japan.)

Two notes are given. The first note deals with completely closed channels and completely open jets of circular section. The second note deals with partly open channels with free segments.

In the first note reference is made to a method due to Burgers which takes account of the so-called attached lines of vorticity and of the curvature of the streamline. Application is made of Watson's method of reducing the resulting series to computable form. Results are given graphically for elliptic, rectangular, and intermediate distribution of vorticity along the span.

The boundary influence of open and closed channels is approximately equal, but of opposite sign, and the problem of determining a partly open channel of zero interference has been considered by various writers to whom references are given.

Elementary approximation place the angle of the segment between 130° and 140°.

Systematic experiments are shown graphically and indicate that a closed segment of 138° nearly brings the experimental values into agreement with the values for a completely closed channel corrected for interference.

Numerical tables of experimental values are given at the end of the paper.

Eighteen references.

Wind Channel Interference. (E. Pistolesi, L'Aerotecnica, Vol. 15, No. 7-8, Aug., 1935 (see Absts. 27093, 28837) pages 697-734.) (11.16/30791 Italy.)

A comprehensive summary is given of the problem in its various forms.

One of Rosenhead's results is slightly lacking in generality, but is easily generalised. This has been done by Janotika.

Seventeen references.

The Oxford Impact Machine. (R. V. Southwell, J. H. Lavery and H. Hallam, Engineering, Vol. 140, No. 3627, 19/7/35, p. 54.) (11.40/30792 Great Britain.)

The apparatus is designed to eliminate the transmission of impact energy to the ground. Both striker and anvil are suspended and the blow is delivered horizontally along a line through the centre of gravity of both. Four point support and application of load produces pure bending. Izod figures are correlated with " Oxford " figures defined as the energy of fracture in foot lbs. per sq. in. of fractured area. As far as present tests indicate, the relationship is linear. Sketches and photographs show general assembly and details of the apparatus.

Two references.

X-Ray Examination of Aircraft Materials. (P. Brenner, Luftwissen, Vol. 2, No. 4, April, 1935, pp. 85-91.) (11.47/30793 Germany.)

A comprehensive report on X-ray examination of structural parts of aeroplanes was published in the D.V.L. Yearbook, 1932.

In the present report some new results are given and lines of further development of existing apparatus are indicated.

Tubes up to 100 kilo-volts suffice for light alloys, timber and thin rods of steel. For thicker steel parts, voltages of 200 kilo-volts and upwards are required. In extreme cases gamma rays must be employed.

A simple installation for testing timber is shown in a sketch and five X-ray photographs are reproduced. Descriptions are given of installations for examining metal parts of different sizes and shapes. Twenty-three photographs and X-ray photographs are reproduced.

Eight references.

Aerostats

New Zeppelin, L.Z. 129. (Sci. Am., Vol. 152, No. 6, June, 1925, pp. 314-315. Flight, Vol. 28, No. 1397, 3/10/35, pp. 352-354.) (12.10/30794 U.S.A.)

Descriptive details of this new airship are supplied by the builders. Length, 815ft.; max. diameter, 134ft.; gas capacity, 6,700,000 cu. ft.; h.p., 4,800; speed, 84 m.p.h. Photographs show the hull under construction and covered. The hull is divided into seventeen gas compartments and the hydrogen cells are surrounded by helium filled spaces. The sections are regular 36-sided polygons throughout and the finished hull shows very clean lines. The four Diesel engines are carried in external gondolas.

Effect of Protective Coatings on the Absorption of Moisture by Gelatin-Latex Gas-Cell Fabrics. (D. F. Houston, Bur. Stan. J. Res., Vol. 15, No. 2, Aug., 1935, pp. 163-172.) (12.42/30795 U.S.A.)

Samples of fabric were submitted by the Goodyear Zeppelin Company.

Paraffin wax coating decreased the rate of absorption of moisture, and coating on both sides was much more effective than coating on one side only.

Aluminium varnish coatings were much heavier and not as effective.

Nine references.

Wireless

Nature of Cosmic Radiation. (T. H. Johnson, J. Frank. Inst., Vol. 220, No. 1, July, 1935, pp. 41-67.) (13.10/30796 U.S.A.)

An observer with suitable nerve responses would be conscious of about 25 cosmic ray shots through some part of the body each second.

These cosmic rays consist of He and H nuclei projected into space by the action of electric fields surrounding the stars. It is concluded that the total energy in the universe in this form exceeds that of starlight and any theories of the universe which fail to incorporate cosmic radiation are necessarily incomplete.

Thirteen references.

A Method of Exciting the Aerial System of a Rotating Radio Beacon. (H. A. Thomas, J. Inst. of Elect. Engineers, Vol. 77, No. 464, Aug., 1935, pp. 285-290.) (13.2/30797 Great Britain.)

Author's Abstract.—This paper describes a novel method of feeding the spaced aerial system of a radio beacon transmitter, which has arisen from the consideration of the possibilities of the application of the Adcock aerial principle to such a beacon. A brief discussion is given of the limitations of the ordinary rotating coil goniometer arrangement for such a beacon when the transmitter power is high.

The alternative method described utilises two power amplifiers to feed the two pairs of spaced aerials. These two amplifiers are supplied with radio-frequency voltages by means of a mechanical controller which automatically provides the required time/voltage variations. A description is given of this controller, together with its application to the problem of exciting the two amplifiers. It is shown that such a controller can fulfil the requirements of the excitation apparatus, and it is concluded that the system described would be suitable for incorporation in a full-size rotating radio beacon for marine navigational purposes.

Monitoring Standard Frequency Emissions. (E. G. Lapham, Proc. Inst. Rad. Eng., Vol. 23, No. 7, July, 1935, pp. 719-732.) (13.30/30798 U.S.A.)

A description gives the method and equipment in use at the National Bureau of Standards.

Graphical records are given showing comparison with N.P.L. primary standards, confirming a frequency variation control of the order of a few units in ten million.

Three references.

Propagation at a Wave-Length of Seventy-Three Centimetres. (B. Trevor and R. W. George, Proc. Inst. Rad. Eng., Vol. 23, No. 5, May, 1935, pp. 461-469.) (13.31/30799 U.S.A.)

Satisfactory communication has been maintained both on the ground and in aircraft over distances up to 100 miles, provided sender and receiver are in the line of sight. With the receiver below the line of sight the field strength diminished very rapidly (approximately as the inverse 9th power of the distance from the sender).

Reception is generally much better at night.

Radio Propagation Over Spherical Earth. (C. R. Burrows, Bell Tele. Pubs. No. B. 869, 1935.) (13.31/30800 U.S.A.)

Abraham's, Watson's and Eckersley's solutions are discussed.

Refraction by lower atmosphere and imperfect conduction of the earth are taken into account.

Measurements of propagation over sea water agree with calculation for a perfectly conducting earth for wave-lengths exceeding 100 metres.

Fifteen references.

Single Sideband Short Wave System for Trans-Atlantic Telephony. (F. A. Polkinghorn and N. F. Schlaack, Proc. Inst. Rad. Eng., Vol. 23, No. 7, July, 1935, pp. 701-718.) (13.31/30801 U.S.A.)

Observations were made on a wave-length of about 30 m. (10,000 k.c.) with an audio frequency range of 250 to 2,800 cycles per sec.

Signal to noise ratio and articulation tests form the basis of a figure of merit.

Figures of merit are plotted against full strength in decibels for double and single side bands and show a substantial superiority of the latter, over the whole range of tests.

Four references.

Ultra-Short Wave Transmission Phenomena. (C. R. Englund, A. B. Crawford and W. W. Mumford, Bell Tele. Pubs. No. B. 870, 1935.) (13.31/30802 U.S.A.)

The main characteristics of short wave transmission are calculated on the principles of geometrical optics up to the range of the ray tangent to the earth's surface. Beyond this range, signals of variable intensity are received and the variations can be correlated with the variations of water vapour content of the atmosphere, and consequent variation in diffraction and refraction.

Records of reception on wave-lengths of 1.58 metres and 4.6 metres during fourteen aeroplane flights are shown graphically in comparison with value calculated on the above hypothesis.

The elementary theory is given in a mathematical appendix.

Diurnal and Seasonal Variations in the Ionosphere, 1933, 1934. (I. P. Schafer and W. M. Goodall, Bell Tele. Pubs. B. 866, 1935.) (13.32/30803 U.S.A.)

Extensive data are exhibited graphically. Correlation is established between magnetic disturbances and decrease in ionisation.

Daily and annual periodicities are established, but phase difference of six hours in the daily period, and six months in the annual period, are shown in different regions.

Detection of Frequency Modulated Waves. (J. G. Chaffee, Bell Tele. Pubs. No. B. 863, 1935.) (13.32/30804 U.S.A.)

The mathematical theory is summarised and approximate series are given for the terms of the expansion in Bessel functions.

Experimental and calculated values are compared graphically and show fundamental agreement in the general run of the characteristics, with numerical divergencies due to the approximate value of the assumptions.

Super-Regeneration of Ultra-Short Wave Receiver (Wave-Length 5 m.). (H. Ataka, Proc. Inst. Rad Eng., Vol. 23, No. 8, Aug., 1935, pp. 841-884.) (13.32/30805 U.S.A.)

From Author's Abstract.—In Part I is developed an analysis of a quenching action, when the quenching electromotive force is assumed to operate by varying sinusoidally the amount of effective resistance of the oscillatory circuit.

In Part II are described the experiments on the quenching action. The stable and the unstable regions of the oscillation under the influence of quenching action are determined.

In Part III are studied the effects of an incoming signal on the receiver. The suppression of the characteristic noise is concluded to be ascribed to a synchronisation of the oscillation in the receiver with that of the incoming signal wave.

In Part IV is considered the amplification by super-regeneration. For too low quenching frequencies, the sensitivity is as low as for too high quenching frequencies. There is an optimum quenching frequency which gives the best sensitivity. There are three important factors which determine the amplification, the quenching frequency, the quenching voltage, and the time of advance by which the oscillation is initiated early in the presence of the signal. A theory of amplification by super-regeneration is developed and the effects of the various factors are considered theoretically.

Eight references.

Detection of Frequency Modulated Waves. (J. G. Chaffee, Proc. Inst. Rad. Eng., Vol. 23, No. 5, May, 1935, pp. 517-540.) (13.32/30806 U.S.A.)

In ultra high frequency modulations a larger number of side bands is introduced and individual measurement of components becomes impracticable.

A general mathematical analysis is given in terms of Bessel functions.

Calculated and measured results are shown graphically for six characteristic relations, and show that the theory is a guide to the general run of observed phenomenas, and gives numerical results which are in substantial agreement, with the exception of limited ranges, in which the simplifying assumptions fail.

Theory of Electron Gun. (I. G. Maloff and D. W. Epstein, Proc. Inst. Rad. Eng., Vol. 22, No. 12, Dec., 1934, pp. 1386-1411.) (13.5/30807 U.S.A.)

The principle of the electron gun is to generate, control and concentrate an electron beam on to a required spot. The theory of electron lenses with detailed analysis of the actions of the various parts of the gun is given.

Five references.

Influence of Impurities in Core-Metal on Thermionic Emission from Oxide Coated Nickel. (M. Benjamin, Phil. Mag., Vol. 20, No. 131, July, 1935, pp. 1-24.) (13.5/30808 Great Britain.)

Nickel of high purity was prepared and small quantities of magnesium, manganese, iron and ferro-titanium, etc., were added.

A vacuum tube was designed to contain two coated cathodes mounted symmetrically to ensure identical conditions. It was found necessary to interpose a sheet nickel screen to prevent deposit of sublimated matter from one cathode on the other.

Extensive data are given in nine diagrams showing emission as a function of time of run and of anode volts.

The phenomena are involved, but it is inferred that emission from barium oxide coated filament depends on the amount of metallic barium present at the surface of the active filament and that this can be purposely affected by the impurities present in the core and diffused into the coating.

Suitable choice of impurities increases the emission substantially.

Thirteen references.

Analysis of the Operation of Vacuum Tubes as Class C Amplifiers. (I. F. Monromtseff and H. N. Kozanowski, Proc. Inst. Rad. Eng., Vol. 23, No. 7, July, 1935, pp. 752-778.) (13.50/30809 U.S.A.)

Constant current charts are prepared on the basis of which output efficiency grid driving power and other factors can be predetermined for three tubes. Oscillograms confirm the computation.

Four references.

Anode Bend Detection. (M. J. O. Strutt, Proc. Inst. Rad. Eng., Vol. 23, No. 8, Aug., 1935, pp. 945-957.) (13.50/30810 U.S.A.)

From Author's Abstract.—The anode direct current versus grid bias voltage characteristic of tubes is developed in the form of a series where two or three terms suffice to represent the curves of some modern commercial tubes quite accurately. By comparison with measured values, detection slope and distortion effects may be accurately calculated from the static tube characteristics. Some general conclusions are obtained regarding the detection of various input waves. Measured and calculated values of detection gain are compared and found to check fairly well.

Three references.

Vacuum Tubes for Generating Frequencies above 100 *Megacycles.* (C. E. Fay and A. L. Samuel, Bell Tele. Pub. No. B. 855, 1935.) (13.50/30811 U.S.A.)

Photographs show a Barkhausen oscillator which maintains a fair output and efficiency up to 580 megacycles.

Fifteen references.

Electrical Characteristics of a Rectifying Film of Lead Sulphide. (W. Schade, Phys. Zeit., Vol. 36, No. 14, 15/7/35, pp. 499-508.) (13.50/30812 Germany.)

A diagram of connections shows the arrangement of the apparatus for separating the rectified and alternating components of the current, as a function of the applied alternating voltage. Cinematograph records of these components are reproduced, and numerical values of the rectified current are plotted graphically over a range in which the current reaches a maximum after which it decreases and reverses.

Eight references.

Amplifying Circuit for Photocells. (E. Einsporn, Phys. Zeit., Vol. 36, No. 10, 15/5/35, pp. 347-356.) (13.70/30813 Germany.)

Amplifying valves for photocells have to respond to small changes in grid voltage. To ensure constancy of electron emission this requires a low filament temperature. Valves possessing desirable characteristics under such conditions are described. They maintain their calibration over long periods.

The Chemistry of the Atomic Nucleus. (S. Flugge and A. Krebs, Phys. Zeit., Vol. 36, No. 13, 1/7/35, pp. 466-480.) (13.70/30814 Germany.)

A résumé of the latest work on protons and neutrons. An extensive bibliography (211 items) covers the period 1921 to date.

Electrical Measurements at Ultra High Frequencies. (R. King, Proc. Inst. Rad. Eng., Vol. 23, No. 8, Aug., 1935, pp. 885-934.) (13.80/30815 U.S.A.)

Author's Abstract.—*Part I.*—A modified form of the long line equations for use at ultra high frequencies is given. A complete solution is obtained for a pair

of parallel wires bridged at each end by a general impedance. The solution is in the form of expressions giving the voltage across and the current through one of these impedances. Conditions are given under which the current or voltage becomes a maximum, as well as formulas for these maximum amplitudes. Special cases are discussed and expressions are derived for use in the measurement of reactance and resistance.

Part II.—A convenient form of parallel wire system for ultra-high frequency measurements is briefly described and its constants are listed. The use of a tandem bridge is explained. The general problem of measuring current and voltage at ultra-high frequencies is considered. A method is mathematically derived for obtaining the calibration characteristics of current and voltage indicators; the method is applied experimentally to determine such characteristics for a thermal milliammeter and for the symmetrical screen grid voltmeter. The scale factor is discussed.

Part III.—The mathematical theory of Part I is applied to obtain two methods for measuring respectively high and low reactances. These are used to measure the reactances of various wires, coils, condensers, thermal milliammeters, vacuum thermo-couples, etc., and to study series and parallel resonance circuits at ultra-high frequencies.

Part IV.—The general problem of resistance at ultra-high frequencies is discussed. The mathematical theory of Part I is applied to the measurement of resistance. Methods are described for measuring the resistances of wires and coils, and of high resistance leaks. A method is suggested for measuring the permeability of wires. Experimental results are given.

Part V.—A method is described for determining the component frequencies present in an ultra-high frequency source, and for measuring their relative amplitudes.

Seventeen references.

Errors Due to "Leads" in Radio Frequency Measurements. (R. M. Davies, Phil. Mag., Vol. 20, No. 131, July, 1935, pp. 75-97.) (13.80/30816 Great Britain.)

Equivalent circuits are specified for a number of circuits occurring in practice, and the current voltage relations are discussed formally.

Numerical examples are worked out and indicate the importance of keeping down inductance in the leads and in making corrections for their effect.

Photography

Absolute Colour Sensitivity of Photographic Layer. (M. Blitz, Phys. Zeit., Vol. 36, No. 16, 15/8/35, pp. 559-563.) (14.60/30817 Germany.)

Previous measurements were made of the density of precipitation at two wave-lengths. The measurements are here extended to the whole visible spectrum.

The apparatus is described and results are plotted for three different photographic films—over the range 400 to 700 mu.

Fourteen references.

The Process of Development in Photography. (W. Neidinger, Phys. Zeit., Vol. 36, No. 9, 14/5/35, pp. 312-320.) (14.60/30818 Germany.)

The process of development is followed under the microscope, using a special Ag. Br. gelatine emulsion. The characteristic of this emulsion lies in the fact that it is very insensitive although containing a high percentage of large grains (6-8u). Over exposure renders the grain less responsive to the developer. The time for reduction, when action has once started, is however the same as for normal exposures.

A series of beautiful micro-photographs illustrate the article.

Ten-Lense Camera. (Aviation, Vol. 34, No. 8, August, 1935, p. 34.) (14.9/30819 U.S.A.)

A brief description is given, with a photograph showing the general appearance of the Fairchild ten-lense camera. Two hundred composite photographs, or two thousand separate photographs, can be taken in one flight.

Acoustics, Noise Reduction, etc.

Origin and Silencing of Aircraft Noise. (K. Krüger, Luftwissen, Vol. 2, No. 7, July, 1935, pp. 171-176.) (15.38/30820 Germany.)

Harmonic analysis gives the so-called tone spectrum of the composite exhaust noise.

A photographic record of a B.M.W. VI six-cylinder engine at 1,800 r.p.m. shows peaks at 85/sec., 190/sec., 255/sec., and so on, the intensity decreasing with frequency. Minor peaks at other frequencies indicate overtones lying between the simple harmonic ratios.

Intensity of propagation in different directions is shown graphically, the polar distribution of intensity being very different for the first five harmonics.

Airscrew noise is discussed on similar lines.

Multi-engined aircraft will give much more complicated intensity distribution.

Air Navigation

Surface Navigation with Bubble Octant. (Lieut.-Cmdr. J. M. Sheehan, U.S.N., U.S. Nav. Inst. Proc., Vol. 61, No. 391, Sept., 1935, pp. 1228-1232.) (15.50/30821 U.S.A.)

The instrument was lent by the Bureau of Aeronautics. On board ship rolling motion made it difficult to effect collimation. Pitching had much less effect. Example of fixes are given and show increasing accuracy with experience.

Simplified Altitude and Z. Azimuth Tables. (C. E. Dazler, U.S. Naval Inst. Proc., Vol. 61, No. 389, July, 1935, pp. 928-933.) (15.50/30822 U.S.A.)

Various tables are compared. Rust's azimuth diagram is preferred by some aviators.

Wind and Ground Speed. (H. H. Strickland, Aero Digest, Vol. 27, No. 2, August, 1935, p. 20.) (15.50/30823 U.S.A.)

Examples of variation of wind with height are shown graphically, and rules are given for pilots to select the most advantageous height on fixed courses.

Savings are estimated at $\frac{1}{4}$ dollar to 1 dollar per flying hour.

Mark VII Navigational Computer for Aircraft. (Lieut.-Col. P. V. H. Weems, U.S.N., Aero Digest, Vol. 26, No. 5, May, 1935, p. 28.) (15.50/30824 U.S.A.)

A graduated circle is mounted so as to rotate on a ruled rectangular sheet. A graduated circular slide rule is supplied. Given wind speed, variation and deviation, the apparent compass course is laid off quickly.

Accidents and Precautions

The Parachute. (H. F. King, Flight, Vol. 28, No. 1390, 15/8/35, p. b-179.) (16.20/30825 Great Britain.)

A descriptive account is given of types of parachutes in use in this country with details of attachments and quick release devices, illustrated by sketches.

Aircraft—Unorthodox

Roof-Top Gyropists. (J. G. Ray, Aviation, Vol. 34, No. 8, August, 1935, pp. 11-14.) (17.05/30826 U.S.A.)

Experimental landings and stallings were made with two direct control autogiros on the roof of the new Philadelphia Post Office with a clear area of 288ft. by 365ft.

Air eddies produced by the wind or by local convection current present difficulties which are discussed.

Three photographs are reproduced.

Gyroplane Sail-Boat. (Sci. American, Vol. 153, No. 3, Sept., 1935, p. 147.) (17.05/30827 U.S.A.)

Two photographs show the complete boat, on the stocks, and sailing.

From the description the two-bladed rotor works on the autogiro principle. It is mounted on a mast and it is stated that the disc inclination is about 17° to the mast.

The mast can be rotated and locked at angular intervals of 6°.

Rocket Propulsion. (Willy Ley, Aircraft Eng., Vol. 7, No. 79, Sept., 1935, pp. 227-231.) (17.2/30828 Great Britain.)

A useful summary is given of the elementary theory. Tables show the ratio of fuel weight to resident load for various final velocities and ranges, the calorific values of hydrogen and other fuels, requiring an external supply of oxygen, and the composition of compounds, such as potassium perchlorate, supplying part of their oxygen.

A description of practical rocket experiments is given, and illustrated by photographs of the apparatus and section sketches of rocket tubes.

Thirty-nine references.

Modern Conceptions about Animal Flight. (Researches by Dr. A. Magnan, reviewed by R. S. Lacape, L'Aérotechnique, No. 151, pp. 61-75, Supplement to L'Aéron., No. 194, July, 1935.) (17.6/30829 France.)

The article deals with the researches of Dr. A. Magnan on the flight of birds and insects.

Flapping flight was studied by means of high speed cinematography, the bird or insect being held by the feet. Smoke pictures were taken of the air flow. There is a strong suction along the back between the wings, and this may account for the forward motion of the wing tips of many birds during the down stroke.

It appears that the wing surface of a bird is normally in excess of requirements and can be reduced by almost 50 per cent. without sensibly affecting performance. If, however, the leading edge is interfered with, flight becomes impossible.

The following table gives some average data:—

	Insect.	Bird.
Number of flaps per second	100	5
Flying speed cm./sec.	400	3,000
Air speed along body between wings (animal held by its feet) cm./sec.	300	1,200
H.P. per 100 kg. of animal weight	3·5	4

According to Dr. Magnan, the air in the vicinity of a flapping wing is in a peculiar turbulent state and ordinary resistance laws can only be applied with caution.

Flight by muscular power seems to be in the realms of possibility for man.

Aircraft Carriers

The Small Cruiser. Carrying Scouting Aircraft. (F. G. Percival, Lieut., late U.S.N., U.S. Nav. Inst. Proc., Vol. 61, No. 387, May, 1935, pp. 641-653.) (18.0/30830 U.S.A.)

The problem is discussed of designing a satisfactory light cruiser of a displacement of 5,000 tons, on the assumption that all naval forces carry scouting aircraft.

Meteorology and Physiology

Upper Air Soundings by Aerograph. (F. J. Nelson, U.S. Naval Inst. Proc., Vol. 61, No. 390, August, 1935, pp. 1140-1144.) (19.10/30831 U.S.A.)

An elementary account is given of the distribution of pressure, temperature and humidity in the troposphere in relation to the weather.

A descriptive account is given of methods of making aeroplane observations with photographs of a combined aerograph and its mounting on an aeroplane.

Weather Editorial. (Canadian Aviation, Vol. 8, No. 8, Aug., 1935, p. 3.) (19.10/30832 Canada.)

Canadian aeronautical weather services are not developed as far as the extensive U.S.A. organisation.

Constructive suggestions are made.

Nature of Nucleus of Hygroscopic Droplets. (J. H. Coste and H. L. Wright, Phil. Mag., Vol. 19, No. 132, Aug., 1935, pp. 209-233.) (19.10/30833 Great Britain.)

The condensation nuclei are predominantly solution of nitrous acid in droplet form. These are produced from the constituents of the air under suitable conditions. Visible flames are not necessary, but contact with a solid surface at temperature of the order of 600°C. will generally suffice.

Nineteen references.

Lightning Currents and Their Variations. (H. Norinder, J. Frank. Inst., Vol. 220, No. 1, July, 1935, pp. 69-92.) (19.10/30834 U.S.A.)

Lightning current is investigated by recording variation in magnetic field in proximity to discharge. The lightning current is pulsating. The maximum current in a pulse is usually of the order of 30,000 amps., the pulse lasting 20 micro-seconds. The total charge transported by the flash seldom exceeds two coulombs.

Six references.

Formation of Ice on Tree-Trunks. (A. Naamann, Phys. Zeit., Vol. 36, No. 12, 15/6/35, pp. 445-447.) (19.15/30835 Germany.)

Sketches of observed ice formations show resemblance to growth of ice on struts and wings. An aerodynamical explanation is suggested.

Mechanical De-Icer Equipment. (Aero Digest, Vol. 27, No. 2, Aug., 1935, pp. 34-35.) (19.15/30836 U.S.A.)

The wing tip is furnished with expansible covering, periodically inflatable as shown in three sketches.

Details of the air driven pump and distributing valve are described.

A Remedy for Air-Sickness. (Sci. Amer., Vol. 153, No. 2, Aug., 1935, p. 91.) (19.29/30837 U.S.A.)

Air sickness can often be cured by making the patient breathe air containing CO_2. A simple way of ensuring this is to breathe in and out of a paper bag. Holding the breath for periods of the order of 15 seconds is also useful.

Ascents into the Stratosphere. (A. Prokfiev, Air. Eng., Vol. 7, No. 79, Sept., 1935, p. 232.) (19.30/30838 Great Britain.)

A brief statement is made of the scientific and technical data which may be sought in stratosphere ascents.

The Problems of Stratosphere Flight. Engine Cooling. (Capt. Rougeron, L'Aeron., No. 194, July, 1935, pp. 187-194.) (19.30/30839 France.)

Stratosphere flight is only of interest if full advantage is taken of the high flying speeds thereby rendered possible. The cooling of engines of the large power output required presents considerable difficulties under these conditions. Normal radiators offer too much resistance and wing radiators are too vulnerable. Direct air cooling is only successful for relatively small power outputs.

(To be continued.)

Equipment

Wind Channel Tests of Model Aerodrome. (Flight, Vol. 28, No. 1396, 26/9/35, p. 343.) (20.20/30840 Great Britain.)

A model was made of Rongotai Aerodrome, N.Z. Wind velocities were measured, and local wind direction observed by steamers attached to wires or posts. The general nature of the air flow agreed with full-scale observation. Eddies from a neighbouring ridge were erratic, and an adjacent valley created a dead spot.

Wind channel experiments indicate that the worst eddies would be mitigated by removing the summit of the ridge and filling up the valley.

Blind Landing. (E. A. Cutrell, Aviation, Vol. 34, No. 8, August, 1935, pp. 22-24.) (20.20/30841 U.S.A.)

Landings by radio beam and by radio compass were carried out at Newark Airport where 99 approaches and 171 completed blind landings were made in six months.

A descriptive account is given with sketches of landing ground layout, and photographs of instrument board and visual indicator.

Light

The Best Illumination for the Examination of Black and White and Colour Prints. (G. Colange, Comptes Rendus., Vol. 201, No. 3, 16/7/35, pp. 204-206.) (21.22/30842 France.)

Generally speaking, oblique illumination increases contrast and will bring out details which are lost under normal incidence. This applies to both colour and black and white prints and is being adopted by museums.

The incidence required is of the order of 20° from the horizontal.

Additive Property of Binocular Vision when Observing Targets and the Advantage of Yellow Beam Searchlight. (A. Blondel, Z. Instrum., No. 6, June, 1935, p. 271. Abstract from Revue d'Optique, Vol. 13, pp. 247-250, 1934.) (21.22/30843 Germany.)

Simultaneous impulses received by both eyes superimpose in the brain according to the same laws (both quantitative and qualitative) as simultaneous

impulses received by a single eye. Binocular vision is therefore superior, provided the observer's eyes taken individually react in a similar manner. In some cases this is not so. The author mentions a case where an observer required an illumination of 600 lux for the left and 800 lux for the right eye, in order to distinguish details which he could observe at 200 lux using both eyes.

Yellow light as an illuminant is a distinct advantage and the author recommends using gilded mirrors for searchlights.

Aerodynamics and Hydrodynamics

Flow in Soil Seepage. (M. G. Ionides, Engineering, Vol. 140, No. 3633, 30/8/35, pp. 211-212.) (22.10/30844 Great Britain.)

In soil which is not too coarse the flow satisfies approximately the (vector) differential equation $\nabla^2 V = 0$.

Photographs of a two-dimensional installation show observed lines of flow corresponding fairly well with the two-dimensional flow of the equation.

On a Method of Measuring Rate of Descent of Solid Spheres in a Viscous Liquid. (M. M. Mahmoud Ghali, Comptes Rendus, Vol. 200, No. 26, 24/6/35, p. 2155.) (22.10/30845 France.)

The descending sphere obstructs a beam of light impinging on a photo cell. The height of drop is 17.4 cm. and times are measured to 1/1,000 sec. Interesting interference results are obtained by dropping spheres in succession or in different groupings.

Analytical Synthesis of Ship Forms. (G. Weinblum, Z.A.M.M., Vol. 15, No. 4, July, 1935, pp. 205-219.) (22.10/30846.)

Following Havelock and Wigley, approximate formulæ of polynomial type and the required integrals thereof are developed in detail.

Numerical examples are shown graphically for a range of selected arbitrary coefficients corresponding to actual ship forms.

The results of the complete integration of resistance are shown graphically and compared with model experiments over a range of speeds from 1 to 5 m./sec.

The general run of the resistance characteristics agrees well, but the peaks in the calculated curve are much more pronounced.

Twelve references.

Theory of Fluid Friction between Shaft and Bearings. (E. Heidebroek, Forschung, Vol. 6, No. 4, July/Aug., 1935, pp. 161-168.) (22.10/30847 Germany.)

Expressions in the form of integrals are obtained for pressure, load and friction, in terms of angular position.

The integrations are carried out and numerical examples are shown graphically. The effects of elastic deformations under high loads introduce difficulties which have not yet been resolved.

Hydrodynamic Analogy of Torsion. (J. P. der Hartog and J. G. McGivern, J. App. Mech., Vol. 2, No. 2, June, 1935, pp. A. 46-A. 48.) (22.10/30848 U.S.A.)

In the well-known Kelvin hydrodynamic analogy, an ideal fluid takes the place of the twisted shaft. The author photographed the potential motion of a practical fluid started from rest before the break up of the boundary layer causes the development of eddies.

Typical photographs obtained by sprinkling Al. powder on the surface of water under these conditions are given.

Five references.

New Bernoulli Theorem. (M. M. Munk, Aero Digest, Vol. 27, No. 2, August, 1935, pp. 28-29.) (22.10/30849 U.S.A.)

A transformation of Bernoulli's theorem is given, in which the velocity enters linearly.

(Continued.)

On the Motion of a Fluid Behind a Sphere. (A. Foch and C. Chartier, Comptes Rendus, Vol. 200, No. 14, 1/4/35, pp. 1178-1181.) (22.10/30850 France.)

The experiments were carried out on a sphere 15 cm. diameter placed in a water channel 50 by 50 cm. Water speeds of between 30 and 200 cm./sec. could be maintained accurately and the flow was studied by means of a special stereoscopic chronographic camera described in C.R., Vol. 197, p. 1642 (1933). Sketches show the variation in flow picture obtained. The author claims that ordinary photographs yield misleading pictures and that the stationary eddy formed can only be studied by stereoscopic means.

Friction of Disc Rotating in Housing. (F. Schultz-Grunow, Z.A.M.M., Vol. 15, No. 4, July, 1935, pp. 191-204.) (22.10/30851.)

Sketches show detail of experimental mounting. The angular speed varied from 50 r.p.m. to 10,000 r.p.m. and the corresponding Reynolds number from 10^4 to 2×10^6.

For lamina flow the equations are soluble by successive approximations. For turbulent flow empirical expressions are introduced and transformed.

Comparison between experiment and calculation is not altogether satisfactory.

Systematic Reduction of Measurement on Ship Steaming and Towing Performances. (G. Kempf, W.R.H., Vol. 16, No. 12, 15/6/35, pp. 189-194.) (22.35/30852 Germany.)

A description is given of instruments for measuring wind velocity and direction, dynamic pressure of relative water velocity with variations due to wave motion. The velocity in the boundary layer is explained and the resistance is analysed. Measurement on rope tension gives the total resistance in the relative stream.

Vorticity Transport in Turbulent Motion. (S. Goldstein, Proc. Camb. Phil. Soc., Vol. 31, No. 3, July, 1935, pp. 351-359.) (22.4/30853 Great Britain.)

The equation of motion of a non-viscous fluid is written down in vector form. The equation obtained by forming the curl of the equation of motion is expanded in cartesian co-ordinates and gives three equations which exhibit the convections of vorticity.

Various general transformations are carried out to the first order of small displacements and formal results are obtained in different ways.

Materials—Elasticity and Plasticity

A Note on the Surface Temperature of Sliding Metals. (F. P. Bowden and K. E. W. Ridler, Proc. Camb. Phil. Soc., Vol. 31, Part 3 (1935), pp. 431-432.) (23.0/30854 Great Britain.)

Surface temperatures are measured directly by using the rubbing contacts of two different metals as a thermo-couple and determining the e.m.f. generated on sliding.

With quite moderate sliding speeds, the e.m.f. generated suggests a temperature rise of several hundred degrees Centigrade.

When using readily fusible metals, the melting temperature is not exceeded, whatever the load and speed of sliding and this is considered proof that true surface temperatures are recorded.

Use of Hele-Shaw Apparatus in Investigation of Flow of Metals. (H. M. Herbert and F. C. Thompson, Engineering, Vol. 140, No. 3637, 27/9/35, pp. 347-349. Paper read to Iron and Steel Institute, 1st September, 1935.) (23.0/30855 Great Britain.)

Photographs of macro structure after drop stamping and drawing, and corresponding photographs of flow in the Hele-Shaw apparatus show marked similarities.

The analogy appears to be qualitative.

Stresses in Radially Loaded Discs. (R. G. Minorili, J. Frank. Inst., Vol. 219, No. 5, May, 1935, pp. 583-596.) (23.0/30856 U.S.A.)

The appropriate form of the elastic equations is solved in trigonometric series. Isoclinics and isochromatics are computed and plotted for a bakelite disc, and comparison with a photoelastic photograph shows substantial agreement.

One reference.

Fields of Tensile Stress in Thin Plates, Initially Curved, Under Shear Load. (H. Wagner and W. Ballerstedt, L.F.F., Vol. 12, No. 2, 16/5/35, pp. 70-74.) (23.3/30857 Germany.)

The elementary equations of elastic equilibrium are applied. A photograph shows an initially circular cylindrical sheet buckling along spirals making about 25° with the axis. Appropriate forms of solution are suggested by experimental work, and take comparatively simple form.

Two cases are discussed analytically, one with closely spaced stiffeners along the generator, the other with closely spaced circular stiffeners perpendicular to the axis.

The numerical result for both cases are shown graphically.

Centre of Shear in a Beam Under a Single Load. (E. Trefftz, Z.A.M.M., Vol. 15, No. 4, July, 1935, pp. 220-225.) (23.3/30858 Germany.)

The equations of elastic equilibrium are formed for simple bending and simple torsion. The corresponding expressions for energy of bending and energy of torsion are formed and superposed to give total strain energy.

The centre of shear is defined and a formal expression is obtained for it, which is independent of Poisson's ratio. The treatment is formal.

Miscellaneous

Pan-American Figures. (Flight, Vol. 28, No. 1390, 15/8/35, pp. 175-177.) (O.G./30859 Great Britain.)

An analysis is given of the amount and application of indirect subsidies to civil aviation in the U.S.A.

Science in the Control of Road Traffic. B.A. Papers and Discussion. (Engineering, Vol. 140, No. 3637, 27/9/35, pp. 332-333.) (O.G./30860 Great Britain.)

The psychological aspect of road accidents is relevant to the corresponding problems in air navigation.

Absorption. (Leading article, Engineering, Vol. 140, No. 3637, 27/9/35, pp. 339-340.) (O.G./30861 Great Britain.)

A brief account is given of typical phenomena, and reference is made to the somewhat conflicting molecular theories put forward.

Application to gas masks, separation of mixtures of rare gases, of oxygen and nitrogen from hydrogen and helium, etc., are mentioned. A satisfactory

general theory has not yet been evolved from the accumulated mass of experimental knowledge.

Smokeless Zone Round a Heated Platinum Ribbon. (S. Miyake, Aer. Res. Inst., Tokyo, Report No. 123, Vol. 10, No. 5, June, 1935.) (O.G./30862 Japan.)

A sketch shows the mounting of the apparatus which consists of a closed vessel of brass (with windows) at the axis of which a platinum strip was mounted. On heating the strip convection currents were set up.

Using smoke of various kinds as indicators, a clear space was observed near the platinum strip and photographed through the window.

Numerous experimental data, tabulated and shown graphically, connect the trend of the smokeless zone with the temperature.

Various physical explanations are discussed and an empirical formula is quoted which gives an approximate fit with the experiment.

Aircraft in the Antarctic. (Lieut.-Cdr. G. O. Neville, Aero Digest, Vol. 26, No. 5, May, 1935, pp. 14-15 and 70.) (O.G./30863 U.S.A.)

A map shows Byrd's base on the Antarctic continent, indicating five extended flights, including one round the South Pole.

Actually 142 flights were made with a total mileage of 13,000 miles. Descriptive details are given.

Theory of Electrostatic Machine. (H. Strauch, Phys. Zeit., No. 17, 1/9/35, pp. 575-584.) (O.G./30864 Germany.)

The separately excited machine is preferred. The main losses are due to corona effects. Attempts to use compressed air or oil as dielectric have not been successful.

Air Resistance of Motor Cars. ("*Farewell to the Horseless Carriage.*") *A Discussion.* (E. G. Reid, S.A.E. Jnl., Vol. 36, No. 5, May, 1935, pp. 180-190.) (O.G./30865 U.S.A.)

Curves of comparative resistance of aeroplanes and motor cars show the importance of air resistance at high wind speeds. Diagrams of power required exhibit the fact that avoidable air resistance absorbs as much as 15 per cent. of the total power required to propel a motor car at 50 m.p.h.

Six references.

REVIEWS

Squadrons of the Royal Air Force

By Major Robertson, Lieut.-Comdr. Colson and F. O. Cook. Published by "Flight." Price 7/6.

This work contains a number of articles on individual squadrons and other units of the Royal Air Force which have already appeared in "Flight," and which are preceded by a short history of military aviation in this country. The book is copiously illustrated by photographs which have been taken by Mr. John Yaxall, whose aerial photographic work is well known.

The book does well that which it sets out to do, and it contains much that is of interest to those who desire to know something about the work of the Royal Air Force. The photographic illustrations are excellent in quality and well chosen. The historical chapter is well written, but one feels that an opportunity has been lost by not illustrating this section with contemporary machines. Not only would this have added a meaning to machine names which convey little or nothing to the younger generations, but it would have given an object lesson on the progress of design.

The book can be thoroughly recommended.

Jane's All the World's Aircraft

Edited by C. G. Gray. Published by Sampson Low. Price £2 2s. 0d.

Apart from its value as a work of reference, each volume of this book sums up the aerial activity of the year and is a most valuable guide to the progress of aeroplane and engine design in every country in the world.

This year again records an increase in the number of types produced in almost every country, as evidenced by the number of pages it has been necessary to allot to each; the greatest increase is to the credit of the British aircraft industry and the pages required have gone up from 67 to 83. This is due, largely, to the extension of the Royal Air Force, but the newer British aircraft building firms have contributed their quota. Other increases are: United States, 76 to 81; France, 45 to 47; and Italy, 23 to 25.

With regard to design, the low wing monoplane has increased in popularity, especially among the newer firms, and the special care taken to abolish all unnecessary resistance is shown by the easy lines of the fuselages, the use of folding undercarriages and the way the wing is faired into the fuselage with large and smooth curves. The high wing monoplane still retains a good deal of popularity, especially in America, but as strutting is commonly used in this type, the machines have not the clean appearance of the low wing aeroplanes. It is noticeable how old-fashioned the conventional type of biplane looks in comparison with these machines, and, although an analysis of the numbers has not been made, it is obvious by inspection that the multiplane types are declining in popularity. In certain developed forms, such as the modern De Havilland machine, improvement in design has given the biplane a new lease of life, though the example of this form in this direction has not been followed by others.

Another exception to the clean lines one expects to find in modern fuselage design is to be seen in the curious shapes of the fuselages of some of the later French bombers. There is no doubt that these peculiarities have been dictated by military considerations, and the designs suggest that performance is not considered so important in comparison with armament as is the case in other countries.

There is not much that is novel in connection with the development of aero engines. The side valve seems to be reappearing in a few types of low powered engines, but the development of the Diesel seems to be at a standstill. Progress seems to be confined to the development of existing ideas and is steady and sure, especially in the alterations necessary to take full advantage of 87 octane fuel.

This fuel has enabled petrol consumptions to be reduced, and power for weight to be increased, and this progress should be continued when 100 octane petrol is available and engines have been built to use it efficiently. The Bristol "Aquela" sleeve valve engine is still the sole representative of its class, and it is probable that the next big advance in aero engine design will come from the use of valves of this type.

With regard to the book itself it is only necessary to say that it is worthy of its predecessors. As a mine of information and an invaluable reference book, it is a necessity to anyone who takes a serious interest in aeronautics.

North to the Orient

By Mrs. A. M. Lindberg. Published by Chatto and Windus. Price 10/6.

This book contains a description of a flight from New York to China by the Great Circle route. It was made by a single-engined seaplane piloted by the author's husband, Colonel Lindberg, with Mrs. Lindberg as wireless operator and crew.

Stories of adventure flights by the pilot are not uncommon, one knows generally what to expect before starting to read, but this is a book describing such a flight which is different from all the others. This difference must be attributed to the personality of the author, which is apparent in everything she writes, from the starting preparations when she was struggling with the intricacies of wireless to the last pages of the book when she is describing her departure from Japan by steamer, the flight having been finished. The result is that the book has that indefinable quality called charm, added to by a perfectly natural freshness of outlook and a facility for choosing the right phrase.

There is little or no technical information, except a list of the equipment carried, but it is difficult to imagine anyone reading the book without keen enjoyment. The moral, if there is one, appears to be that, fundamentally, human beings are the same all over the world, in the east as well as in the west, in spite of the well-known quotation from Kipling.

I do not know whether this is Mrs. Lindberg's first attempt at authorship, but whether this is so or not she has proved that she can strike a new and most delightful literary note. I know that all those who read her book will hope for more, and that is the finest compliment which can be paid to any author.

Symposium on the Welding of Iron and Steel

Published at the Offices of the Iron and Steel Institute. £2 2s. 0d.

In May, 1935, a symposium on the welding of iron and steel was organised by the Iron and Steel Institute in conjunction with other societies, including the Royal Aeronautical Society, and the two volumes of this work contain the proceedings. The first volume deals with present-day practice, and problems of welding in the engineering industries, while the second deals with welding practice and technique, apparatus, metallurgy, inspection and testing, etc.

These two volumes contain the most complete information on welding which has so far been published. Almost all branches are included, and there are papers on welding in connection with shipbuilding, on repairing bridges, locomotives, and on fabricating almost every article required by engineers. Many of the papers have been written by men well known in engineering circles, both here and abroad, for foreign practice is well represented.

Papers are included on the welding of aircraft structures by J. B. Johnson, of the War Dept., Dayton, Ohio, U.S.A.; by J. Roosenschoon, of Holland; by H. Sutton, of the R.A.E.; and by R. F. Taylor, of Messrs. A. V. Roe. Among other contributors well known in aeronautical circles are Dr. Gough, Dr. Hatfield, Prof. Coker and G. A. Hankin, who has an interesting paper on the fatigue of welds, a matter which has possibly not received in the past as much attention as it deserves.

The book is invaluable to those interested in the subject.

The 600th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

A meeting of the Society was held in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, on Monday, December 16th, 1935. In the chair: Mr. H. E. Wimperis (Director of Scientific Research, Air Ministry, Vice-President of the Society).

The late Sir Richard Glazebrook

The Chairman: He asked the audience to stand, and announced with deep regret the sudden death of Sir Richard Glazebrook. He recalled that Sir Richard had been Chairman of the Aeronautical Research Committee since its foundation, that he was the first Director, and practically the founder, of the National Physical Laboratory, and Gold Medallist of the Royal Aeronautical Society. The whole membership of the Society, he said, would share the general feeling of regret at a death of so eminent a member of the profession.

Introducing Captain J. M. Furnival, who presented a paper on "Wireless and its Application to Commercial Aviation," he said that he had been concerned with radio work in the R.F.C. and R.A.F. during the great war; after the war he had joined the Marconi Company, in 1923 he was Manager of the Aircraft Department of that Company, and at the moment was in charge of the Marconi Aircraft Wireless Establishment at Hackbridge, which establishment was concerned with the development, design and manufacture of all kinds of aircraft radio apparatus. As part of its manifold duties, the Company had sole charge of the work of providing the wireless equipments for Imperial Airways, Ltd., with its many ramifications; so that Captain Furnival was amply qualified to deal with the developments of aircraft radio work.

WIRELESS AND ITS APPLICATION TO COMMERCIAL AVIATION

BY

Captain J. M. FURNIVAL, M.B.E., A.F.R.Ae.S.

I. Introduction

Already wireless is playing an extremely important part in connection with the smooth and safe operation of the commercial aviation services of to-day and it is evident that the present-day trend is to place more and more reliance upon wireless aids for the achievements of that regularity of service in all weathers, which is looked upon as necessary for the ultimate success of truly commercial aviation.

It seems therefore desirable to review at the present juncture the functioning of wireless communication and direction finding systems as used by the commercial air services; to consider some of the problems with which designers and operators are faced, and to bring to light the limitations and possibilities of this medium of communication and direction finding, both in respect to present and future requirements.

II. Wave-length Characteristics

As is well known, transmission through the ether can be effected by the use of electro-magnetic waves of various wave-lengths or frequencies. These range from very long waves of the order of 30,000 metres to very short waves of the order of a fraction of a metre in length.

The physical conditions governing the propagation of these waves differ with the frequency or wave-length employed, with the result that careful selection is necessary in order to choose the most suitable wave-length for the class of service required.

As a medium of communication, transmission by means of electro-magnetic waves through the ether is subject to certain vagaries and uncertainties, the extent and nature of which are functions of the wave-length employed. Considerable research into these matters is necessary so that the degree of reliability of any service can be forecast within reasonable limits and the best wave-length selected to give the desired result.

In connection with point to point telegraph or telephone services conducted by wireless, the daily volume of traffic can be disposed of without appreciable detriment to reliability by changes to wave-lengths giving known performance and by the use of alternative routes, and by such means overall guarantees of traffic capacity can be maintained in spite of vagaries due to physical circumstances over which the engineer has no control.

Where aircraft services are involved, however, and where safety of life is at stake, different circumstances arise because it may not be possible to wait any appreciable time for a wave-length change, which is rendered more difficult in selection by the fact that an aeroplane is not a fixed point, and no alternative route for transmission is generally possible. This amounts to what wireless engineers would call a " twenty-four-hour in the day guarantee," that is to say, when a call is made, it is expected that an immediate reply will be forthcoming at any time of the day or night. This is an extremely stringent requirement and therefore the proper selection of wave-lengths for aeronautical services and a true knowledge of their limitations and peculiarities is of fundamental importance, particularly when it is intended to place great reliance on this method of communication, such as is called for when using wireless as an aid to the bringing of aircraft into the home port in conditions of poor visibility as a regular routine.

It is not possible to do any more than to touch briefly on the outline of this subject within the scope of a paper such as this, but it will perhaps suffice if the main points of interest to the aeronautical engineer are brought to light.

By the C.C.I.R. Conference at the Hague in 1929, the range of wave-lengths was divided as follows:—

Waves above 3,000 metres were classified as Long Waves.
Those lying between the limits of 200 and 3,000 metres as Medium Waves.
Between 50 and 200 metres as Intermediate Waves.
Those between 10 and 50 metres as Short Waves.
Those below 10 metres as Ultra-Short Waves.

For the transmission of long waves, physically large plant and aerials are required. Hence, it is not possible to employ these wave-lengths for transmitting messages from aircraft to ground.

The medium wave band provides wave-lengths suitable for covering moderate distances, and it is these waves which are mainly used for broadcasting, marine and aeronautical services, the actual distribution and allotment being regulated by international agreement. At the Warsaw Conference of 1934, the band allotted for aircraft communications was 822-938 metres.

Generally speaking and with certain limitations, the medium wave-lengths are found to be suitable both for aeronautical communication and direction finding services.

In tropical regions, interference from atmospherics, the amount of which depends upon the time of the day and the season of the year, greatly limits the usefulness of the service obtained from these wave-lengths, but in Europe this interference, although liable to be severe at times, is not sufficiently serious to impair appreciably the overall efficiency of the service on the wave-lengths or frequencies allocated for aeronautical purposes.

These wave-lengths are subject to night error which affects the accuracy of bearings taken on medium wave direction finders. As is well known, this is due to the reflection of these waves from the Ionosphere.

Until the advent of the Marconi-Adcock Direction Finder, by means of which device the reflected and unwanted rays can be to a great extent eliminated, this characteristic greatly impaired the value of the navigational service obtainable during the hours of darkness and particularly during the periods of sunrise and sunset.

As the whole of the present aeronautical communication and direction finding services of the European network and the internal services of Great Britain employ medium wave-lengths within the narrow band allocated by international agreement, viz., 822-938 metres, one of the great problems of the moment is the fact that there are not enough channels adequately to carry the very large amount of traffic which has developed as services have increased in extent and frequency.

For this reason, there is a trend towards the employment of intermediate wave-lengths, that is to say, those falling below 200 metres, for the local communications which are required in connection with the developing inland air services in this country. There are obvious possibilities in the employment of such waves, and the following considerations may help to indicate their possible applications and utility.

Transmission may take place from the aeroplane with D.F. aids on the ground or vice-versa. With the amount of power available in the aircraft, it is estimated from research data that ranges of about 200 kms. over land, from a height of, say, 6,000ft., would be possible when receiving on a ground direction finder. Over sea, this distance would be doubled.

Alternatively, assistance to navigation can be effected by carrying a simple form of directional receiver on the aircraft and there are certain possibilities here, at any rate during daylight hours.

The curves (Fig. 1) show predicted performances, assuming the power radiated by the ground station to be of the order of 1 k.w. A1 and A2 show the field intensity at the aeroplane for over-land transmission, A1 at ground level and A2 at 2,000 metres height. B1 and B2 give similar curves for transmission over sea.

In the case of transmission over land, at a distance of 350 kms. in winter, reflection from the Ionosphere sets in and at great ranges the fields are variable, but direction finding would not suffer appreciably during daylight hours.

During night, at ranges beyond 120 kms. over land and 350 kms. over sea the ray reflected from the Ionosphere is equal to, or greater than the direct ray. Under such conditions, bad night errors will occur when receiving with a loop on an aircraft.

Short wave-lengths, that is to say, those lying between the limits of 10 and 50 metres, are subject to still greater attenuation of the direct ray over the earth's surface, whereas reflection from the Ionosphere is still more pronounced. The distance from the transmitter at which the reflected ray arrives at the earth's surface varies with the wave-length employed and with the time of the day or

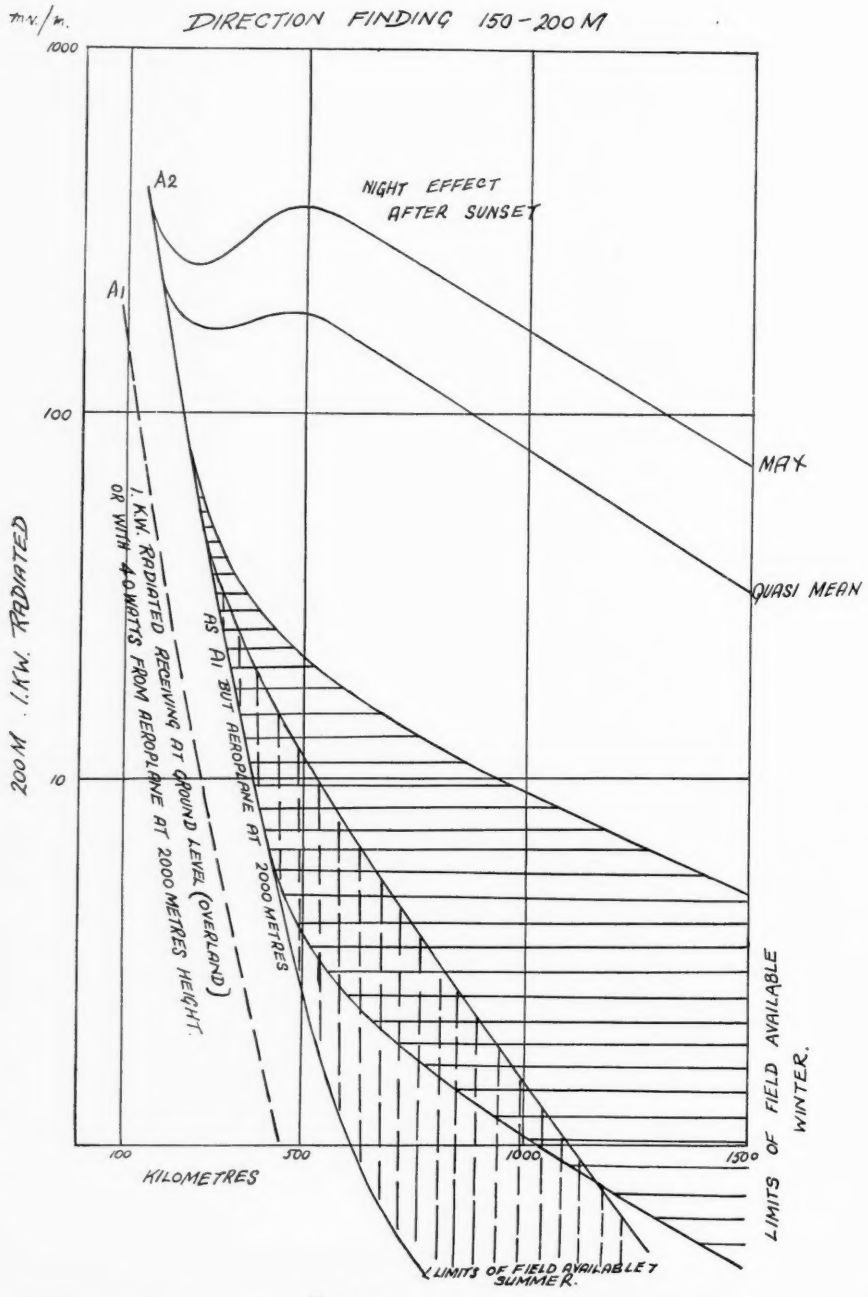


FIG. 1A.

General characteristics governing the propagation of intermediate wave-lengths.

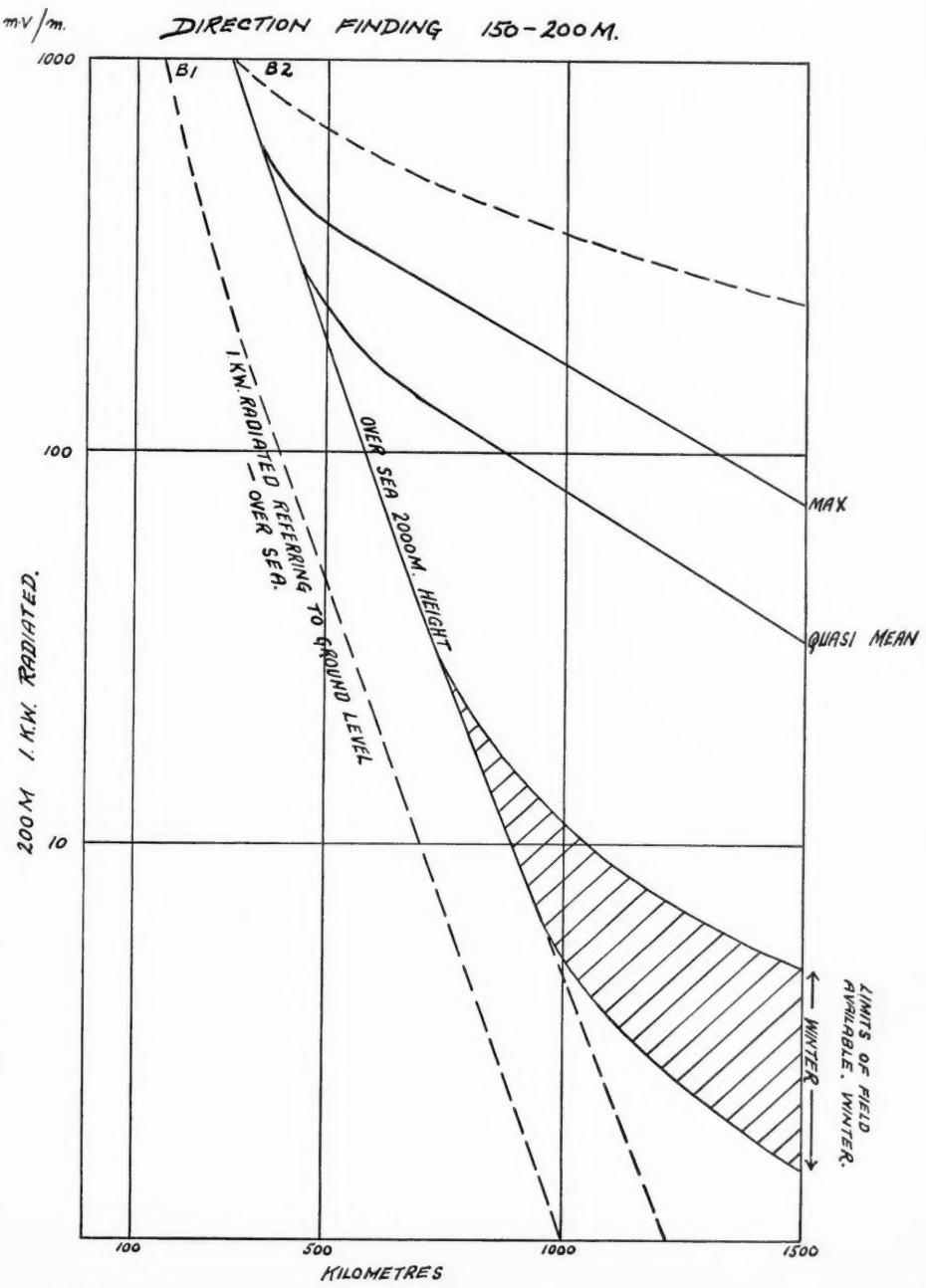

mV/m.
DIRECTION FINDING 150-200 M.
1000
100
10
B1
B2
1 KW. RADIATED OVER SEA.
REFERRING TO GROUND LEVEL
OVER SEA 2000 M. HEIGHT
MAX
QUASI MEAN
200 M 1 K.W. RADIATED.
WINTER
LIMITS OF FIELD AVAILABLE. WINTER.
100
500
1000
1500
KILOMETRES

FIG. 1B.

night. This distance is also subject to seasonal and regional variation. There is usually to be found a gap or skip distance within which the direct ray has diminished while the indirect ray has not yet returned to the earth's surface. Fig. 2 shows this effect.

It will be seen that the reflected ray can be received over very great distances and advantage is taken of this property by the short wave beam telegraph and telephone services which now connect the world's important traffic centres.

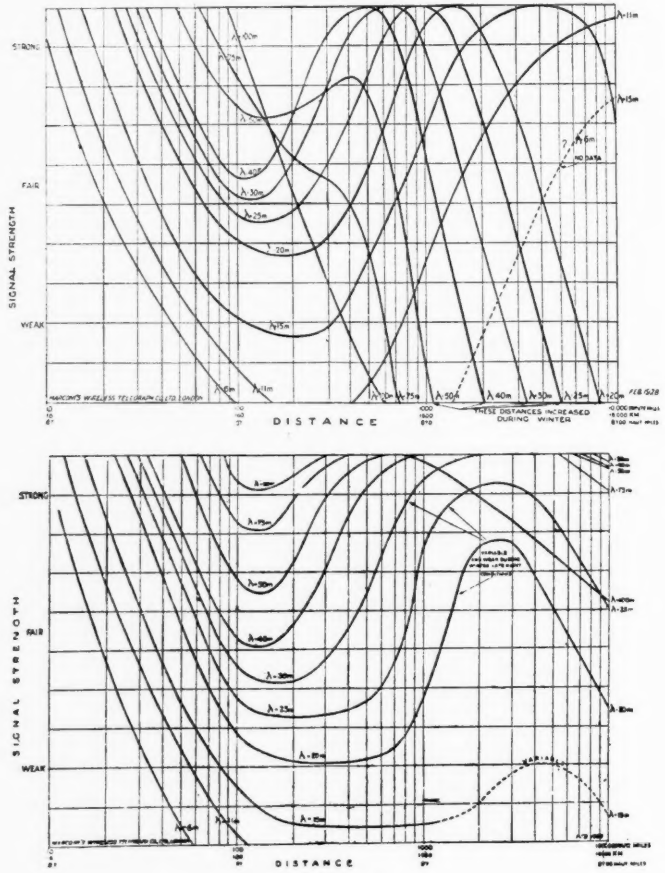


FIG. 2.

Skip effect.

The physical dimensions of the transmitting equipment and the aerial system required for the transmission of short wave-lengths are small and permit of easy installation in aircraft, and hence these wave-lengths have considerable and growing importance in connection with aviation services, particularly as it has been found that they are relatively free from those atmospheric disturbances

which so greatly impair the effectiveness of medium wave communication in tropical regions.

The propagation of short (and also intermediate) wave-lengths is such that they will freely follow the optical path between any two points, and this effect is of considerable importance and advantage when communicating between ground stations and aircraft flying at fairly high altitudes.

As the aeroplane gains height, so the direct ray between it and the ground station is strengthened and this has the result of minimising the skip phenomenon.

The practical result is that aircraft communications carried out on short wave-lengths are less susceptible to skip effects than would be the case for ground station working.

Because of the freedom of these waves from atmospheric interference, they are in common use in the tropical regions of the world's long distance air routes. After daily practical trials over a period of six months on sections of the African air route, it was shown that a wave of the order of 45 metres was generally suitable for daylight use for normal route communication, and this wave-length is now in general use; it is but little affected by skip and covers distances up to 1,000 miles or more with but small power.

Owing to the fact that the reflected waves arrive at many different angles, it has not hitherto been possible to employ these waves for direction finding services in the same manner as in the case of medium and long wave-lengths, and up to the present time the aircraft on the Empire services are equipped, therefore, for both medium and short wave transmission and reception. However, for many years past, a considerable measure of research has been directed to the investigation of the properties and the propagation phenomena of these short wave-lengths, and as a result of this work attention is now being advantageously directed to means for employing short waves for direction finding in connection with the long distance trans-oceanic routes of the future. Considerable progress has been made in this direction and the results are sufficiently promising to indicate that a degree of reliability sufficient for the needs of the service will be obtainable when taking bearings either at close ranges on the direct ray or at long ranges on the indirect ray, and that there is a fair chance that the skip distance within which difficulties are encountered will not be too extensive, if flying is maintained at a reasonable altitude, say, above 2,000ft.

The problem of accurate direction finding depends on the elimination of the unwanted ray. This can be effected by means of an Adcock system or by arranging the transmitting signal in the form of a series of pulses, it being possible by this means to detect and take a bearing upon the direct ray which arrives a fraction of a second in advance of the indirect ray owing to the shorter path taken.

This and other alternative methods have been under practical observation during recent months, a series of tests having been conducted, using a normal service short wave transmitter fitted with a special pulse sending device and installed by kind co-operation of Imperial Airways, Ltd., on one of their cross-Channel aircraft (see Fig. 3).

Short wave receivers, whilst enjoying immunity from atmospheric interference, are generally more susceptible than medium wave receivers to " man made static," that is to say, interference noise generated in proximity to the apparatus by electric equipment, such as magnetos, generating sets, etc., and it is necessary to take the well-known precautions of thorough screening and bonding in order to obtain a clear and undisturbed background.

Ultra-short waves are still more attenuated than short waves as they pass over the earth's surface and are normally free from reflection from the Ionosphere. The optical or " height effect " is very pronounced, that is to say, if the aircraft

is at such a height as to subtend an angle approximately 1° or more with the station on the ground, the rays will follow this free path without considerable attenuation. These wave-lengths are not subject to atmospheric interference and for these several reasons are particularly suitable for local " approach " services, to which they will in the future be extensively applied. The wave-length internationally favoured for " approach " beacons is 9 metres, which is the

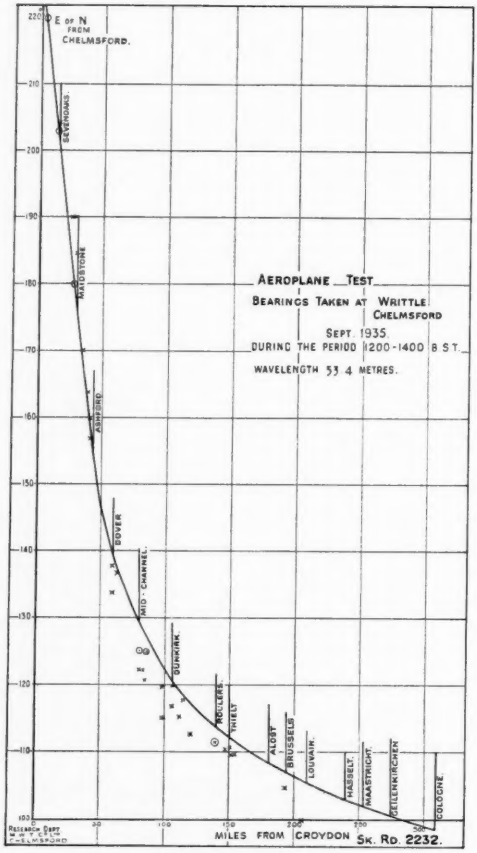


FIG. 3A.

Short wave direction finding curves.

longest convenient wave in the ultra-short wave band. The physical dimensions of the transmitting and aerial system are small and waves can be concentrated into sharply defined beams, which are now being applied to the guiding of aircraft into aerodromes under conditions of bad visibility, both in the horizontal and vertical planes.

Future research may reveal possibilities of harnessing for the use of aviation the very short wave-lengths known as quasi-optical or micro-waves. These waves

require still smaller apparatus and aerials and may perhaps play an important part in the future in the actual landing of aircraft in conditions of poor visibility or for the warning of the dangerous proximity of one aircraft to another.

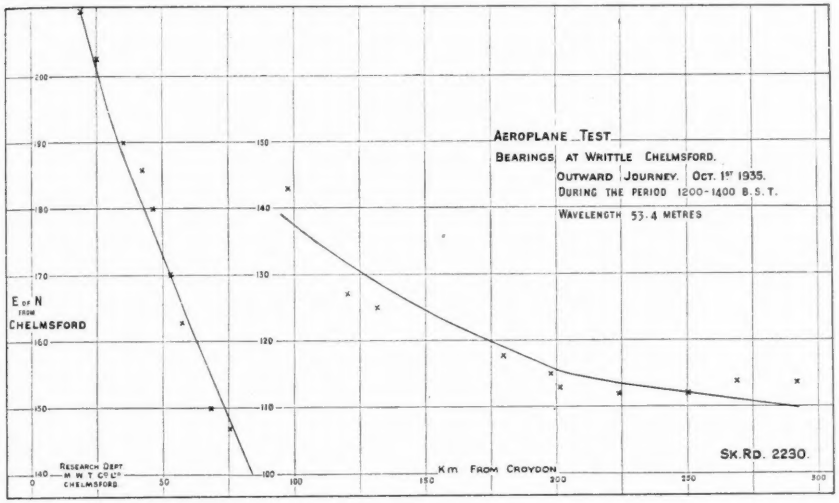


FIG. 3B.

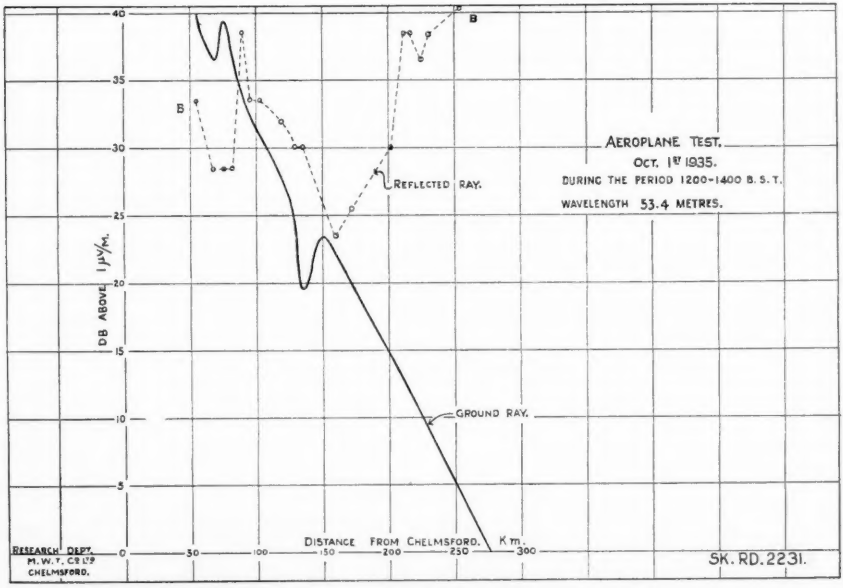


FIG. 3C.

III. Communication Systems

Since wireless was first employed as a means of linking aircraft with ground stations, both telegraphy and telephony have been freely employed, each system having its particular field of use. At the present time, the generally accepted method, wherever possible, is to send messages by telegraphy, employing an abbreviated code of signals and using hand speed Morse, allowing of the passage of 20-25 words per minute. On point to point land station circuits, telegraphic speeds of up to 400 words per minute are attained by the use of automatic senders, but the additional equipment which would have to be carried on aircraft is hardly justified under present-day conditions, since a considerable staff is required to handle traffic received at such speeds and the additional apparatus is weighty.

The advantages of the telegraph system are very great. For any given range, the apparatus required is lighter and cheaper than that required for telephony. The continuous wave system occupies a narrower channel in the ether, thereby using to the best possible advantage the restricted band available for aeronautical services. A higher degree of accuracy is obtainable than in the case of the spoken word and a remarkable speed of operation is achieved by the use of concise abbreviated codes. Furthermore, the language difficulty is avoided. For these reasons, one finds that telegraphy is generally employed for communication throughout the European network of routes and on the long distance air routes throughout the world.

In medium size aircraft, where a second pilot must in any case be carried, it is possible to economise in personnel by training the second pilot or first officer to the required degree of proficiency in the sending and receiving of Morse messages, but the standard of working demanded by present-day conditions really demands the whole time concentration of a professional telegraphist.

On the other hand, there has been found a field of usefulness for wireless telephony, and indeed this method of working was for many years employed almost entirely on the British cross-Channel services and undoubtedly rendered great service, often under difficult and unfavourable conditions. The advantages of this form of communication are that, firstly, it is possible for the pilot himself to effect the communication and thus save the weight and cost of employment of a telegraphist. Secondly, under favourable conditions, the passage of messages can be effected very quickly and there is no delay in the transcribing and passing forward of the message to the pilot—he gets it direct. It is possible for information to be exchanged at a speed of perhaps 100 words per minute, compared with, say, 20-25 words per minute possible by hand speed telegraphy. This advantage is of sufficient importance to warrant the added complication of the accessories required for telephony, even in equipment to be installed in large aircraft where it is known that a telegraphist will always be carried, the particular requirement catered for being landing instructions and close range work where direct contact between the pilot and the ground station is of immediate importance.

The possibility of dispensing with the weight of the wireless operator reacts in favour of the use of wireless telephony in small aircraft operating internal and special charter services where the language difficulty is not a deterrent and where economy in the operating costs of small aircraft is of paramount importance. Nevertheless, it must be stated that there has recently been a tendency, even in small aircraft, to carry a telegraphist during winter months where regular services have to be performed in all kinds of weather. The reason for this is that, on the one hand, the pilot cannot devote the required attention from his flying duties under such arduous conditions, and, on the other hand, the need for reliable weather reports and bearings becomes even more essential if regular schedules are to be maintained. Communication engineers do not favour

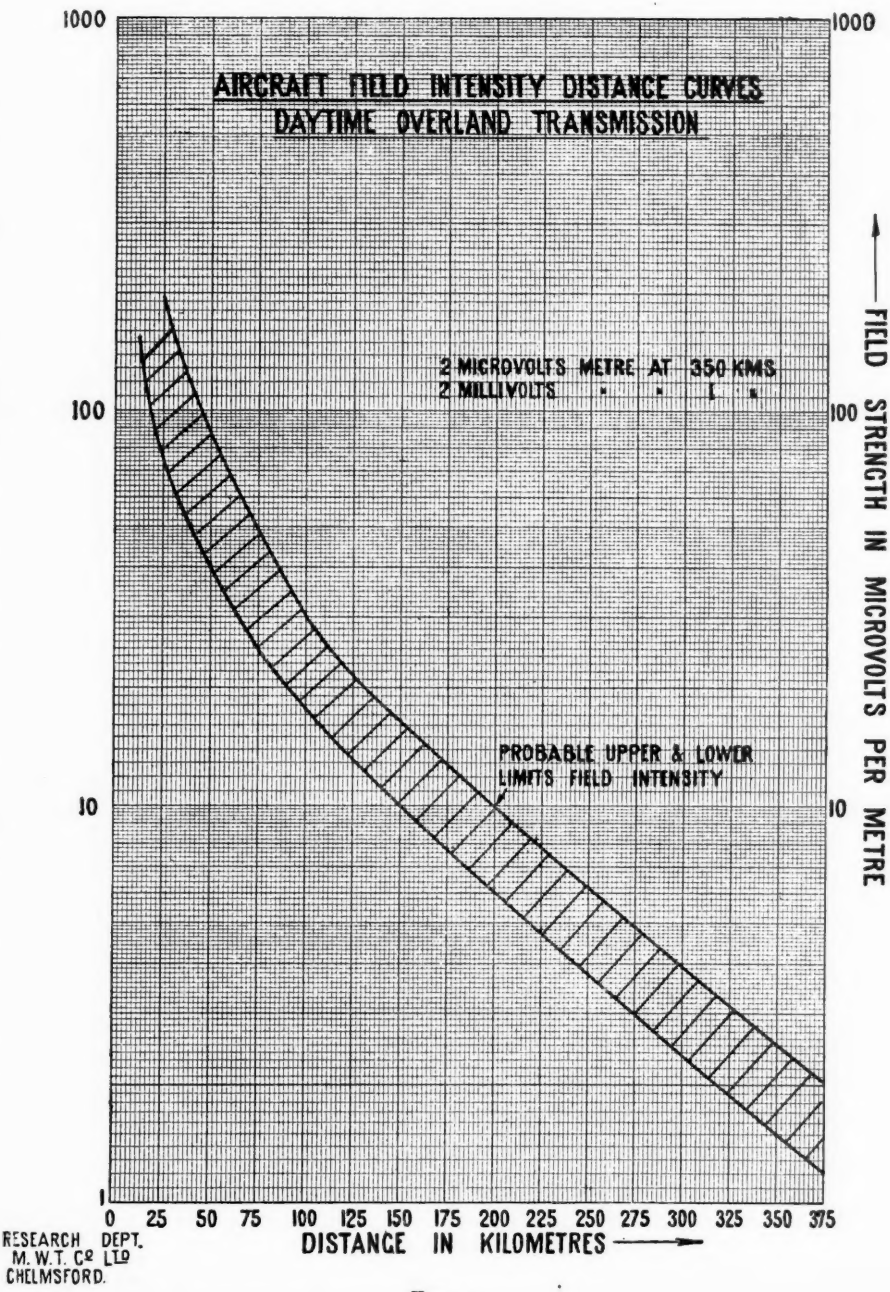

AIRCRAFT FIELD INTENSITY DISTANCE CURVES
DAYTIME OVERLAND TRANSMISSION
2 MICROVOLTS METRE AT 350 KMS
2 MILLIVOLTS " " 1 "
PROBABLE UPPER & LOWER LIMITS FIELD INTENSITY
1000
100
10
1
FIELD STRENGTH IN MICROVOLTS PER METRE
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375
DISTANCE IN KILOMETRES
RESEARCH DEPT.
M. W. T. Co LTD
CHELMSFORD.

FIG. 4.

Field strength curves for medium wave aircraft transmission.

telephony because of the extra interference caused by its use and by the possibilities of inaccuracy arising from the misunderstanding of words, but to the aeronautical engineer, concerned with speed and pay load, the possibilities of an efficient telephony service make a very definite appeal.

These facts have been realised very well in America where wireless telephony is used to much the same extent on the United States trans-Continental services as telegraphy is used on the Continent of Europe.

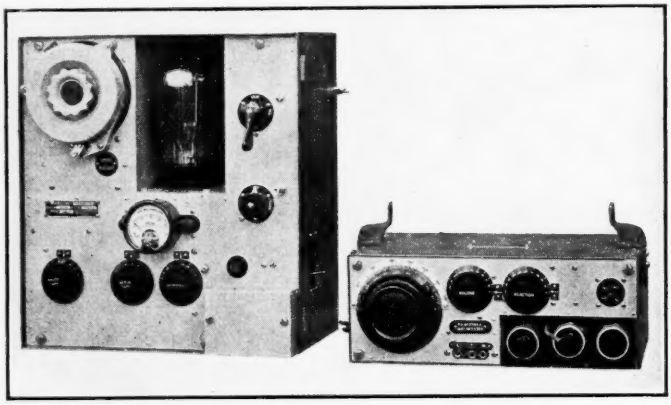


FIG. 5.
Telegraph-telephone medium wave set.
Marconi Type AD. 49/50.

The very extensive use and the importance attached to this form of service in America has enforced a high degree of development, leading to reliability and speed of operation, and it is found in actual practice that the continual use of an effective telephone link direct between pilot and ground, operated in conjunction with the " A and N " equi-signal beacon system regularly marking the routes along which the pilot must fly, has a good effect in establishing a feeling of confidence in the mind of the flying personnel with beneficial effect to the service.

Fig. 4 shows graphically the field strength obtained from an average powered medium wave aircraft transmitter at various distances. The average aircraft receiving system requires about 10 micro-volts per metre for good reception of C.W. telegraph and about 50 micro-volts per metre for telephone signals. The ground receiver requires less signal intensity owing to the more favourable operating conditions.

Fig. 5 shows a modern telephone-telegraph medium wave transmitting and receiving set suitable for use on inland and certain European routes. Fig. 6 shows a combined medium wave and short wave telegraph and telephone set designed for use on Empire airways, where, as explained, short waves are employed in certain regions in order to maintain communication through severe atmospheric interference and over long distances.

As will be dealt with more fully in the next section of the paper, the aeronautical wave-lengths in Europe and elsewhere used for communication purposes are also employed for direction finding and this fact undoubtedly contributes to a considerable extent to the congestion of traffic experienced during busy periods.

The American authorities have developed their system along different lines and employ those medium wave-lengths which are best suited for direction finding, mainly for this purpose, and use an entirely different set of wave-lengths —intermediate wave-lengths ranging between 50 and 100 metres, which are not so suitable for direction finding—for their telephony communication system.

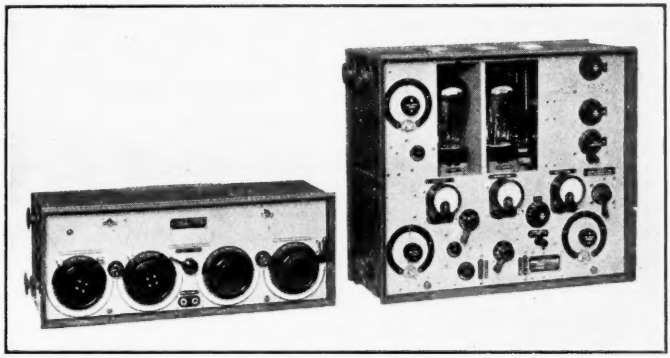


FIG. 6.

Combined medium wave and short wave telegraph-telephone set. Marconi Type AD. 37/38.

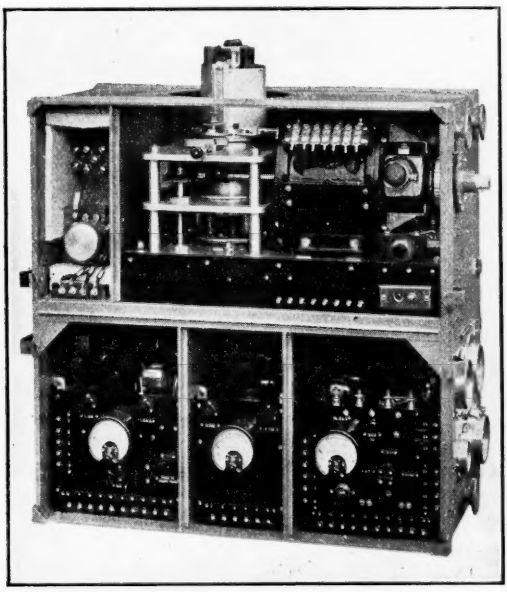


FIG. 7A.

Facsimile transmitting apparatus.

There is much to be said for this arrangement provided the necessary wavelengths are available.

Before leaving the subject of communications, the method of broadcasting information must not be overlooked. Economy in transmission can often be obtained by this means, which is used for the dissemination of meteorological reports receivable by any machine carrying a suitable wireless receiving set. Examples of this method are to be found in the Department of Commerce system in America, and in the British Air Ministry Meteorological Broadcasting Station at Borough Hill.

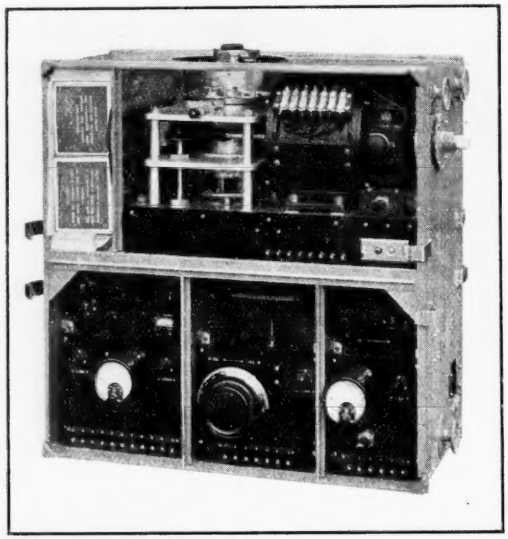


FIG. 7B.
Facsimile receiving apparatus.

It may be of passing interest to observe that there has been developed an alternative method of conveying intelligence both to the telegraphic and telephonic systems, that is, the facsimile transmission of written messages, charts or diagrams. Fig. 7 shows the actual apparatus developed and Fig. 8 an example of a message transmitted by this means. It is possible that such a system might have a useful application in the sending of meteorological charts to aircraft, and particularly airships, engaged on long distance non-stop flights.

IV. DIRECTIONAL SYSTEMS

It is in conjunction with aerial navigation that wireless is called upon to play a most important part, calling for the highest technique in its various applications.

Broadly speaking, there have grown up three distinct systems, each differing in marked degree from the other. They are:—

(*a*) The system of ground direction finders, which has been developed to serve the present-day European network and Empire services.
(*b*) The system of directional equi-signal beacons established to mark the chain of air routes throughout the U.S.A.

(*c*) The system of homing, first used on Empire routes and now coming to the fore as an aid to the itinerant flyer.

Each of these systems employs or has been developed from the basic properties of the simple loop of wire which, when turned around on its vertical axis in the field transmitted from a wireless station, is responsive thereto in varying extent according to its orientation in respect of the direction of the wave front, the maximum response being when the plane of the loop is in line in the direction of travel of the waves—this being a rather broad indication—and at a sharp minimum when at right angles to the direction of the waves.

Supplementing these services there are now coming into being, supplementary "approach" or short range directive aids intended for guiding aircraft to the confines of the airport after the vicinity has been reached by the use of long distance navigational systems.

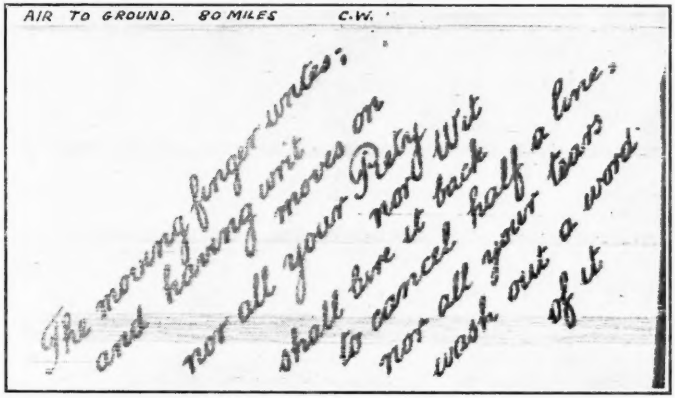


FIG. 8.

Example of message sent by facsimile apparatus.

As is well known, the European network is now a highly organised system comprising direction finding receivers installed at the main airports and also at other specially selected sites, associated with suitable transmitting equipment for passing the bearings taken from aircraft transmissions by the ground receiving station back to the aircraft, and for inter-communication with other co-operating stations for determining the position of the aircraft by triangulation. This system is well suited to serve a network of routes as distinct from a chain, but is liable to suffer from overloading and consequent delays under increasing traffic density. A large percentage of the load will be removed by the establishment of the supplementary approach system, as the giving of a continuous service of bearings to aircraft approaching an airport under conditions of bad visibility makes the most severe demand on the service and is liable to cause interference over a wide area. This has led to a separate channel being allotted for serving the needs of the Croydon aerodrome for controlled zone operations.

Relieved of this load, it is likely that the ground D.F. service will continue to act as a normal and efficient guiding system for European routes for many years to come.

The system of navigation by means of direction finders acts as a most valuable guard on the cross-Channel routes, since, only by this means can a fixed

or positive position be determined in the event of an aircraft sending out a fleeting S.O.S. and subsequently being forced down.

According to the figures published in the Report on the Progress of Civil Aviation for 1934, the number of bearings and magnetic reciprocals passed, and positions given to aircraft from Croydon last year totalled no less than 14,585.

So much has already been written concerning the equi-signal beacon system as developed in America that a detailed description of its functions appears unnecessary.

Stations are erected at the main airports and in certain cases at intermediate points for the purpose of marking courses or tracks along the routes to be flown. The pilot listens to the signal emitted; when on course a continuous musical note is heard; when off course this becomes broken into Morse characters indicating A on the one side and N on the other, signal definition becoming more and more pronounced as the distance from the true course increases. Means have also been developed for indication by visual means, although the aural method is still in common use.

These beacons usually mark four courses, the angular displacement being at 90° to each other, but capable of certain adjustments to meet the needs of routes served. The number of courses can be reduced to two or increased even to twelve by elaboration of equipment. The junction point of two tracks is indicated by a " marker " beacon, the wireless equivalent of a light beacon, and stages along the route may also thus be indicated.

Main and marker beacons can be arranged periodically to send telephone broadcasts for the dissemination of weather and other relevant information.

Originally it was envisaged that, by the aid of such a system, it would suffice for a receiving set only to be carried in the aircraft, with resulting economy in weight and cost to the transport companies. Now, however, it is realised that full transmitting and receiving facilities are required so that in many cases, in addition to the beacon receiver, a separate transmitting and receiving set is also installed, using wave-lengths which do not interfere with those allocated to the beacon service. Thus, these aircraft carry two receivers and one transmitter and this results in a rather more complex aircraft equipment than is required for the European system, this arrangement having its counterpart at the airport station.

In certain conditions and over mountainous country, the courses have been found to suffer from bending or splitting. This effect was also noticed to a small extent during the test of the Croydon equi-signal beacon in the vicinity of Sevenoaks, when a distinct bend, due to the nature, or contours, of the ground, and possibly aided by the proximity of power lines, was consistently observed (see Fig. 9).

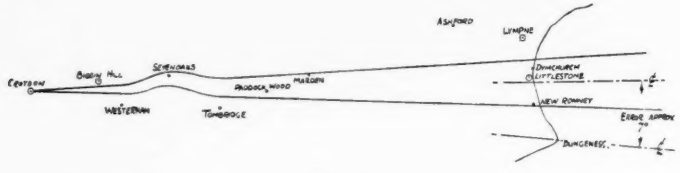


FIG. 9.

The effect of hilly country on equi-signal beacon course.

The long range equi-signal system has undoubtedly been developed to serve in a highly efficient manner the needs of the American route organisation for which it appears to be particularly well adapted; that is to say, when high traffic density and long overland routes have to be catered for by a chain of stations. It is doubtful if there is an equally suitable and parallel field of application else-

where, having regard to individual route requirements, first cost and to the present-day state of development of alternative methods.

By the system of ground direction finding and also by the equi-signal method, directional determination is a function of the ground station, but there is the alternative of carrying a directional receiver in the aircraft, thereby permitting the navigator to determine his own bearing or position from any fixed land stations within the range of his receiver. The system is one which has certain obvious advantages and is rapidly developing at the present time.

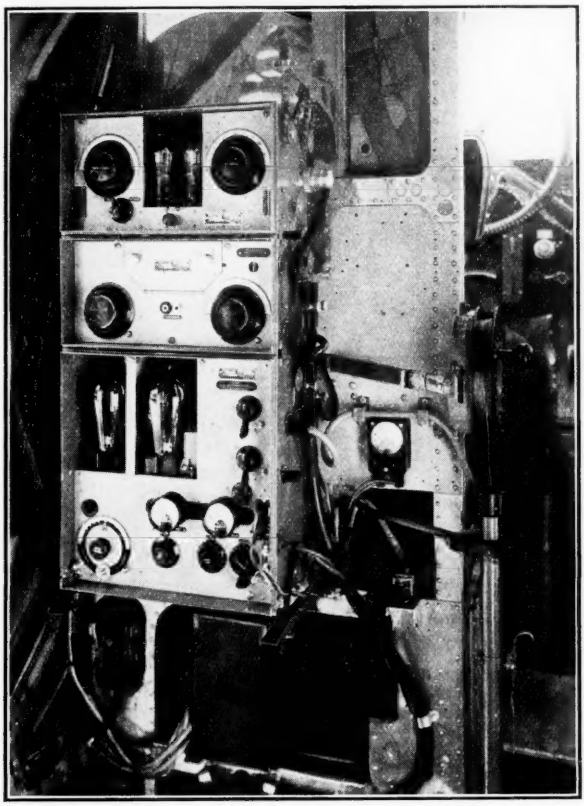


FIG 10.

Homing equipment combined with medium wave service transmitter and receiver.

To obtain a full direction finding service, it is usual to instal an external circular loop which can be rotated and orientated by the operator when taking a bearing. The bearing must be observed in relation to the magnetic compass reading and the resultant laid off on a chart. By taking bearings in quick succession on two or more stations, an actual position can be fixed.

The process is one requiring some skill and practice to co-ordinate the senses of touch, for the adjustment of the instrument; of sound, in identifying the station and its directional indication; and of sight, in simultaneously observing the compass reading.

Hence, such a system is mainly suitable for large craft where such conditions can be adequately provided, in other words, where a skilled telegraphist can be carried on board under conditions which will allow him to effect these operations.

There is, however, a valuable and interesting alternative, that is to say, the homing method, in connection with which a fixed directional loop placed athwartship is provided, and the pilot is able, by aural or visual indication, to steer the aircraft in a direct line—presupposing conditions of still air—towards the wireless station to which he desires to direct his course.

FIG. 11.
Homing equipment loop.

To allow for drift, it is arranged in some systems to adjust the loop to a compensating angle, while other systems provide, by means of a dashboard instrument, an off-course indicator approximately calibrated.

Of the two alternatives, the adjustable loop is preferable in larger aircraft since this permits both homing and direction services to be carried out if an operator is available, and a very useful combination results. Furthermore, it is preferable to use the purely visual indicator in conjunction with a station emitting a continuous transmission, *i.e.*, a broadcasting station, and whilst convenient for pilot operation in areas thus served, provides too restricted a service where there is a member of the crew qualified as a wireless operator.

Figs. 10 and 11 show a form of homing equipment combined with the medium wave service transmitter and receiver, designed for air route requirements, while Fig. 12 shows the effect of drift upon the course flown.

Briefly reviewing these various methods of navigation, it would seem that, whereas the equi-signal beacon method is well adapted to serve the needs of busy overland routes where a chain of such stations can be effectively installed, the direction finding receiving system is more adaptable to meet the needs of a network, especially if supplemented by approach beacons where traffic requirements would otherwise overload the system.

Alternative to the above, there is the method of direction finding in aircraft.

One important factor differentiates the first two from the last method mentioned, and that is the phenomenon of night effect, for whereas methods of avoiding this potent source of error are available to land stations, no practical method has as yet been applied to the aircraft direction finder, and until this time arrives, reliance for accurate determination of bearings at a distance during night flying must rest with the ground station service—night effect is not as a

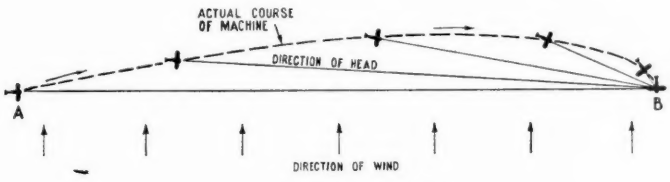


FIG. 12.

Effect of drift.

rule serious within distances of 50 miles from the station from which the bearing is taken. Fig. 13 shows curves of night effect observed simultaneously on Bellini Tosi and Adcock direction finding stations.

Fig. 14 shows a theoretical scheme of equi-signal beacon stations as they would have to be installed to serve inland air routes. It will be noted that ten main beacons and fifteen marker beacons would be required according to the plan, but the finding of suitable frequencies for such a scheme without interference from and with the European organisation would present a serious problem. A compromise plan, however, can be envisaged on the basis of an ultra-short wave approach system supplemented by a service of bearings from existing direction finding stations to cover the longer distances outside the service zones of the ultra-short wave beacons.

V. APPROACH SYSTEMS

There are at least three methods differing in principle which it will be interesting to consider. The first one depends upon the passing of observed data—bearings and proximity—to the pilot from the Control Station at the aerodrome at which the landing is to be made. The aircraft arrives in the vicinity and is advised of this fact by the personnel of the ground station, who hear the noise of the engines; it turns about and proceeds away from the field in the direction in which the approach for landing should be made. From this point—a few minutes' flying time—the aircraft is guided during its final approach by a series of bearings communicated from the ground station. This system, developed in Germany, utilises existing equipment and is more fully described in Dr. Stüssel's lecture before the Society in April of 1934. It can be regarded as provisional pending the development and application of more precise aids. Nevertheless, by its means valuable assistance has been rendered to aircraft on many occasions.

The next method to consider is that by which a small wireless beacon—equivalent to a light beacon—is installed at the approach to the aerodrome runway and directional equipment provided in the aeroplane—a homing receiver and directional gyro—which is used by the pilot to enable him to steer a course which will guide him to the runway track.

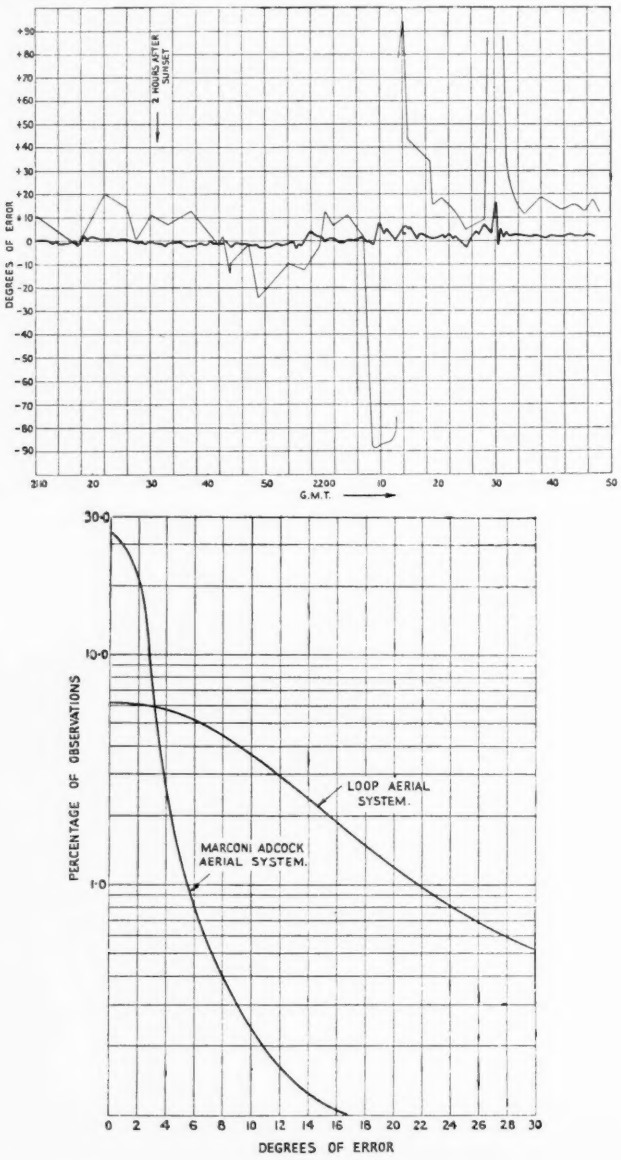


FIG 13

Marconi-Adcock and Bellini Tosi night effect curves.

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FIG. 14

Theoretical scheme of equi-signal beacons to serve inland routes.

Guidance in the vertical plane is also a matter left for the pilot's determination by the use of a sensitive altimeter pre-set to the correct barometric pressure from information received by wireless from the aerodrome and by means of which the height of the aeroplane above the ground is adjusted at the required distance from the runway track to allow of a landing being made after following the natural gliding angle of the machine from the point at which the height adjustment is fixed. This point is marked by a " marker " beacon situated at a distance of, say, two miles from the aerodrome.

As an additional check, a second marker, designed to emit a sharply defined ultra-short wave field pattern in the form of a curtain, is installed to indicate the boundary of the aerodrome over which the aircraft must pass in order to reach the runway.

In the third system, the directional guidance in both horizontal and, with limits, in the vertical plane, is given automatically from the ground in the form of a track to be followed by the approaching aircraft. The pilot is provided with a simple indicating apparatus which will show him when he is following the desired track.

In regard to the three systems described, the first one (known as the ZZ system) requires individual and co-operative operation between the pilot and the ground staff for each landing attempted. In the second case, beacon equipment is provided, but directional determination is the responsibility of the pilot. In the third system, directional guidance is automatically furnished by the special beacon apparatus provided.

Dealing with the equipment required for each of these three systems, the first method utilises the existing apparatus used for ordinary navigational purposes.

For the second method, two small power medium wave omni-directional beacons are provided, working in conjunction with an ultra-short wave marker beacon. In addition to a homing receiver, the aircraft must be fitted with ultra-short wave apparatus for receiving the signals from the marker beacon.

The third system in one version employs ultra-short wave marker beacons and an ultra-short wave track beacon designed to project in the direction of the approach course two overlapping beams, of which one is sent out in a series of long dashes and the other in a series of short dots.

Where the two beams overlap with equal signal intensity, a continuous dash is received. Dashboard instruments are provided to indicate to the pilot the signals received from each marker in turn and to enable the pilot to follow the track of the main beacon.

By utilising very short wave-lengths for this purpose, it is possible to project the beam in a vertical plane so that the line of equal field strength along its lower edge approximates as closely as possible to the natural gliding angle of the aeroplane. An additional dashboard instrument is provided which indicates the field strength which must be received by the aircraft receiver if the correct angle of glide—following the contour of the beam is to be followed; thus, both horizontal and vertical guidance can be given, but, whereas the necessary degree of precision can be guaranteed in regard to horizontal gliding, more experience has yet to be gained in the problem of vertical guidance before it will be safe for airport authorities to announce the availability of these facilities.

In another version, medium waves are used for the equi-signal track beacon and for the markers. With this arrangement, no form of vertical guidance is given, unless a separate ultra-short wave beam is provided for the purpose, as in original American experiments.

Of the various methods described, the ZZ system and the ultra-short wave track system with its markers have been developed in Germany.

According to present methods, the main beacon actually marks two courses, one at 180° from the other. The system has been under investigation in this

country for some time past and means have been devised by a special arrangement of aerials whereby the unwanted back radiation is eliminated. Beacons having these characteristics are to be tried at the Croydon and Gatwick Airports.

The method by which the track is marked by a medium wave equi-signal beacon has been successfully used in Holland and the long range equi-signal beacon installed at the Croydon Airport is being modified for approach work on similar lines. Another medium wave approach beacon with its markers is being installed at the Liverpool Airport. These aids have the great advantage of requiring no additional equipment to be carried in the aircraft.

The other method described is that now being sponsored by the American authorities.

What degree of success the pilot will be able to achieve with the aids that the wireless engineers are able to place at his disposal is a matter for further determination and much careful exploration, particularly in regard to vertical guidance, and in this connection it must be borne in mind that the wireless beam cannot be regarded as a solid diagram with sharply defined boundaries.

VI. Design of Aircraft and Airport Installations

Aircraft Installations

The lay-out of the wireless installation of the modern commercial aircraft calls for a consideration of the following items:—

1. *The Aerial System.*

As many as five different aerials may have to be installed, namely:—

(*a*) A trailing aerial for long distance medium wave and short wave communication.

(*b*) A supplementary fixed aerial for close range working in flight and for emergency operations on land or water.

(*c*) A directional aerial for homing and direction finding.

(*d*) A vertical aerial for the ultra-short wave track beacon receiver, when fitted.

(*e*) A horizontal dipole aerial for the ultra-short wave marker beacon receiver, when fitted.

Dealing with each of these items in turn, the details of the trailing aerial are so well known that comment is hardly necessary. It is of interest to observe, however, that this form of aerial is tending to become rather less efficient as a radiator as the speed of flight increases. This is because the increase in drag on the aerial reduces its effective " electrical height " in relation to the aircraft, as the aerial tends to lie horizontally.

The use of a trailing aerial during certain atmospheric conditions increases the risk of a lightning discharge and a protector or earthing switch fitted externally is desirable.

As aircraft increase in size, permitting of the installation of a more effective fixed aerial, it may be possible to dispense with the trailing system, but at present this is still of great value in conserving the power required to cover long distances, because of its properties as an effective radiator. The present-day trailing aerial system comprises a hand-operated winch with automatic release, and a fairlead allowing of the complete retraction of the aerial, the fairlead itself being retractable where installed in the hull of a boat.

The fixed aerial may take the form of a single wire from a short kingpost adjacent to the wireless installation to a suitable point of attachment on the tail fin to which extension wires to the wing tips may be added where medium waves are used on small and medium sized aircraft.

In the case of flying boats, it is desirable to provide means for elevating the fixed aerial to the maximum height for effective transmission whilst on the water.

The directional aerial in the case of metal aircraft must be fitted externally. It is usual to instal a rotatable loop capable of orientation by the operator by means of suitable controlling mechanism. In certain cases, means are provided for retracting the loop when it is not actually in use.

In aircraft of mixed construction, it is possible to avoid the drag of the loop by fitting wing or fuselage coils, but in this case it is usual to provide only a service of homing.

In regard to the ultra-short wave aerials, the vertical one can often be constructed as an integral component of the fixed aerial kingpost, whilst the dipole must be disposed on the underneath side of the fuselage a few inches away from the skin in a fore and aft line.

2. *The Apparatus.*

It has been, and in certain cases still is, the practice in British commercial aircraft to instal the wireless apparatus in a part of the machine out of reach of the operator, and to provide remote controls for the various adjustments and switches.

Modern service requirements, however, necessitate an ever increasing number of operations to be performed. These comprise:—

(*a*) The changing over from transmit to receive.
(*b*) Receiving adjustment.
(*c*) Change from fixed to trailing aerial.
(*d*) Change from plain to directional reception.
(*e*) Directional receiver and aerial adjustment.
(*f*) Change from telegraphy to telephony.
(*g*) Selection of one of several wave-lengths.

In addition to the above requirements, provision must be envisaged for switching on and monitoring the ultra-short wave receiving apparatus when it is installed. Hence, it is now usual to allocate a space for wireless equipment immediately behind the first or second pilot, but in front of the forward cabin bulkhead. In this position, the apparatus can be under the direct control of the wireless operator, if one be carried, or by partial remote control, or alternatively by direct control by the second pilot by turning his seat.

In large aircraft, a separate wireless cabin may be provided where all equipment and controls are centralised, enabling separate D.F. and communication watches to be maintained as required.

In smaller aircraft having a single seat cockpit a useful combination is obtained by installing the equipment in the cabin immediately behind the forward bulkhead, thereby permitting of remote control by the pilot during the favourable flying season and direct control by the professional operator in bad weather periods.

3. *Power Supply.*

Power for driving the generator during flight can be obtained either from the air stream by windmill generator, or from the aircraft L.T. system through a convertor, or by direct drive from one of the main engines.

It is a fundamental requirement of wireless equipment that it must be available for instant service at any time, and this aspect becomes a vital issue in the event of engine failure involving a forced descent. Under such circumstances, it is highly desirable for the distress call to be transmitted during the transitory period whilst the aircraft is air borne, this to ensure effective radiation from the aerial system.

Compliance with this requirement almost limits the choice of power source to the windmill drive or accumulator battery of the aircraft L.T. system.

The increase in speed of the modern aircraft causes the drag introduced by carrying an external generator and windmill to become a serious factor. Where,

however, this method is employed, the mounting of the generator in the leading edge of the wing is usually favoured, this generator providing energy both for wireless transmission and for the L.T. supply for lighting, engine starting, etc. Regulation is arranged by automatic variable pitch windmill.

As, however, it is now becoming general practice to provide aircraft engines with directly driven low tension generators for the electrical services of the aircraft, it becomes immediately possible to design the wireless installation so as to utilise this source of energy and there is a considerable present-day trend in this direction, high tension anode convertors (which must be flame proof) being supplied for the wireless transmitting and receiving apparatus, reliance being placed on the main accumulator battery for a reserve of power in case of emergency.

For aircraft flying over long distances, the emergency power is catered for by the supply of a light weight petrol engine arranged to drive the wireless generator direct, or alternatively to be used as a power source for charging the aircraft battery.

4. *Bonding and Screening.*

The advent of short wave and directional services necessitates the provision of receivers which are rather sensitive to interference noises and it is necessary that a sound bonding and screening specification should be followed. Bonding requirements are sufficiently well known to need no comment.

In regard to screening, we seem to have come to a stage where, with small additional development work, the ignition system of the engine could be fully screened as standard.

Satisfactorily screened magnetos and plugs appear to be available, but further improvement in the screening and protection of the connecting leads and their associated fittings is indicated, and too much emphasis cannot be given to this important matter. Very effective screening and bonding is common-place on American and German aircraft.

Interference is liable to be caused not only through the ignition system, but also from the lighting and charging circuits, and it would be sound practice to encase this wiring also in light metal sheathing, using gland nut fittings for termination as on the American system, this being sound both from a mechanical and from a wireless point of view.

Airport Installations

In regard to airport requirements, the wireless equipment must be firstly considered in relation to the main organisation of which it will form a part.

Service requirements and site considerations call for a detailed examination of each case, and the study of the problems involved would fully occupy a separate paper devoted to this particular subject. One or two points, however, may here be included.

The wireless equipment of an airport naturally falls under two headings, namely, the transmitting and the receiving plant.

The transmitting plant may comprise one or more transmitters, and it is the accepted practice to locate this equipment outside the confines of the airport and to operate it remotely from the aerodrome control station.

The modern transmitter is designed in such a manner that it can operate for long periods without attention provided a proper maintenance routine be arranged.

The starting up of the transmitter, the selection of various types of transmission, keying, speaking and change from one pre-selected wave-length to another, are all operations which can be effected by remote control.

A site for the transmitting station should be reserved at such a distance from the airport that the towers for supporting the aerials, which may average 100ft. in height, will not form an obstruction to the approach.

In regard to the receiving equipment, the main problem to be considered is the site for the direction finding receiver. If, as is likely, night flying will have to be catered for by the use of an Adcock direction finder, the question of site selection is of great importance. The four Adcock aerials are placed at the corners of a square, the distance between the diagonals being approximately one-tenth of a wave-length. The site must be reasonably clear of conductive obstructions, buildings, etc., for as great a distance as possible from the aerial.

It is often desirable, even if appearances are favourable, to make an actual check of the suitability of the site by means of temporary testing equipment.

The service requirements of the modern airport D.F. receiving station may call for the operation of more than one channel simultaneously. It is now possible in the case of the Marconi Adcock station, as a result of recent development work, to carry out a direction finding service with two receivers working simultaneously on a common aerial system without mutual interference. The frequency separation can be as little as 5 kcs. and only slight interference is

FIG. 15A.
Transmitting apparatus for airports.
Marconi Type TA. 2.

observed when operating on the same frequency or wave-length. This method allows of considerable economy in space and first cost, and facilitates the centralisation of control at the D.F. site. It is, however, necessary for the aerial system to be situated at some distance from the airport administration because of site considerations, and means are being developed for providing a satisfactory method whereby the instrumental operation may be effected away from the actual aerial system in order to enable the D.F. operator to work in a locality more conveniently situated to the airport control.

It will be seen from the above that the planning of the wireless equipment of an airport is a matter which should not be attempted without opportunity for full examination and consultation between the airport authorities, those responsible for the route organisation and the contractor who is to supply the wireless equipment.

Figs. 15A and 15B show typical transmitting and receiving apparatus for airports, and Fig. 16 shows an example of an Adcock aerial system.

VII. Control of Wireless for Aviation

Agreement between the nations as to the apportionment of wave bands between various services is effected through the medium of the Radiotelegraphic Convention, the last conference being that held at Madrid in 1932. The next will be held at Cairo in 1938.

International agreement on matters concerning aeronautical services (including wireless) is effected through the medium of the International Commission for Air Navigation, and the " International Aeronautical Conferences," both of which meet annually.

National control extends not only to measures for regulating the use of wavelengths within the bands which have been internationally allotted, but also provides an all-embracing system of technical and operational supervision.

Furthermore, the Air Ministry reserves to itself entirely the provision and operation of the whole of the extensive wireless ground organisation existing in this country to-day to serve the needs of cross-Channel and inland services.

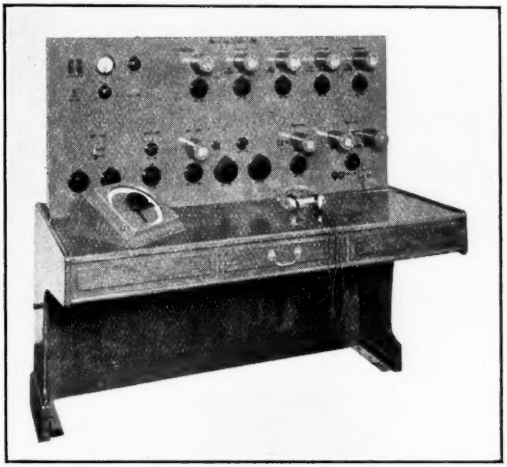


Fig. 15B.

Receiving apparatus for airports.
Marconi Type DFG. 10.

Details of these services are published in the Report on the Progress of Civil Aviation, issued yearly by the Air Ministry, and in the " Air Pilot " and its supplements, and Notices to Airmen.

The system of supervision and control over the supply and operation of wireless apparatus in commercial aircraft is effected by the following means:—

Firstly, it is necessary for the aircraft operator, who wishes to employ wireless transmitting and receiving apparatus to apply to the Air Ministry for permission to use wireless and for technical approval of the apparatus and method of installation proposed, and then for the licence to be obtained from the Postmaster-General. If receiving apparatus only is required it is only necessary for installation approval from the Air Ministry and a G.P.O. licence to be obtained. Licences to operate transmitters using the aeronautical frequencies are not freely issued to private users unless there are good grounds for granting such a licence.

Secondly, it is necessary that all radio-telegraphy and telephony operators should hold an operating licence issued by the Postmaster-General after they have passed the required examination in accordance with the published syllabus.

The licensing of the equipment and the operation thereof, taken in conjunction with the functioning of the ground organisation, provides the Governmental method of operational control.

Technical supervision is exercised by the following methods:—

Firstly, the type of equipment must be approved by the Air Ministry. Individual types of equipment produced by commercial firms may be submitted for approval, or the Air Ministry may approve certain firms as competent for the design of wireless apparatus for commercial aircraft, in which case a certificate of suitability, covering each type produced by such firms, must be submitted.

Secondly, the installation of the approved type must also be approved by the Air Ministry, and any subsequent modification to the installation must likewise be approved. The act of approval may be carried out by the Air Ministry entirely or may be delegated jointly to the supplying firm (who will be approved for installation design) and the approved aircraft constructor, in which case a

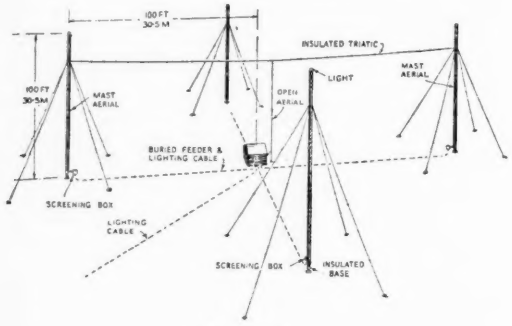


FIG. 16.

Marconi-Adcock aerial system.

certificate and lay-out drawings have to be rendered. *Note.*—Receiving apparatus alone only requires installation approval.

The manufacture of the apparatus itself is also subject to supervision through the A.I.D., who must be satisfied that any equipment for use on British commercial aircraft is constructed of approved materials and in accordance with the drawings and specifications of the approved design. This supervision may be effected by inspection during manufacture and test at the makers' works or by the approval of suitable firms for the manufacture of such apparatus, in which case the firm's inspecting officials act on behalf of the A.I.D. in releasing the apparatus for service.

In addition to the exercise of their authority in the above manner, the Air Ministry lay down certain specific requirements which are promulgated from time to time in design leaflets and which cover a variety of points of design detail.

It is now customary, however, for such requirements to be submitted to the manufacturers through the medium of the Society of British Aircraft Constructors for agreement before promulgation.

Another way in which the Air Ministry exercise technical supervision is by the holding of periodical investigations with the supply and operating companies into the results actually being obtained in service. At these investigations, every cause of failure to effect satisfactory communication is examined in detail, the cause diagnosed and the remedy advocated. This system is of much benefit

to the proper functioning of the maintenance organisation now in operation, which, by painstaking efforts and effective routine, enables a very high degree of reliability to be guaranteed to the aircraft operator.

VIII. Comparison of Aeronautical and Marine Wireless Services

In reviewing the functions now performed by wireless for commercial aviation, the question naturally comes to mind, "What are future developments going to bring?" Developments in the science of wireless are so rapid and far-reaching that it is not easy to make any such forecast, but it will be of interest and may be relevant to see how wireless services for aviation compare with those which have been subject to thirty years' development in connection with the Mercantile Marine.

Firstly, in regard to communication services, ships at sea employ a medium wave-length of 600 metres internationally for service communication and distress calls. This wave is supplemented by other waves of 705 metres, 800 metres, and from 1,895 to 2,400 metres.

Small craft, such as trawlers, employ waves within the band of 109 to 200 metres and use telephony extensively. The object in using telephony is, of course, to avoid the cost of carrying a professional telegraphist in these small vessels.

In regard to direction finding service, originally this was effected by providing positions and bearings from shore stations, but latterly the use of direction finding instruments on board ships has developed on such an extensive scale that the giving of bearings and positions from shore stations no longer plays such a prominent part in marine navigation.

In order to enable the mariner to obtain a full and proper service from his direction finder, automatic omni-directional beacons are installed at suitable points along the coast line. These beacons are installed at lighthouses and on board lightships and are arranged to work automatically with virtually unskilled attention. They operate in groups of three, using wave-lengths within the band 950 to 1,050 metres, mutual interference being avoided by a combination of wave-lengths, note frequency and time selection. Each beacon is under clock control and is provided with a code sender for automatically transmitting the characteristic call sign. Twenty-five of these beacons are in service around the coast of Great Britain.

Such is the value now attributed to the marine direction finder that the fitting of these instruments is compulsory on passenger ships of over 5,000 tons gross.

Not long ago, interesting experiments were conducted in order to demonstrate how very short wave-lengths (micro waves) could be employed for guiding ships into harbour.

Medium wave directional beacons are in use, but in the case of marine services, these are of the rotating type, examples being at Orford Ness and Rangoon. Power from the beacon energises a frame aerial which rotates at one revolution per minute, the bearing being observed by checking the time between the hearing of the characteristic signal at due north and the passing of the minimum. This type of beacon was first developed by the Air Ministry for aircraft navigation.

A large proportion of the telegraph traffic from ship stations is concerned with the transmission of private telegrams. Equivalent services are now available on certain of the European and long distance air routes for the benefit of passengers requiring these facilities.

Supplementary equipment on board ship comprises a service of entertainment through loudspeaking equipment for music, etc., and also for announcements for passengers by the captain. It would be quite practicable to provide lightweight

receiving and amplifying equipment on large air liners for the benefit of passengers flying over long distances.

Another important device which is now being extensively used in the Mercantile Marine is the depth sounder. The apparatus generates waves which are projected from the hull of the ship and reflected from the bottom of the ocean, and means are provided for measuring the time interval between the transmission of the signal and the return echo.

Certain of the large trans-Atlantic vessels are equipped with radio-telephony apparatus, working on short wave-lengths, by means of which passengers are able to call up subscribers to the public telephone services on shore.

A news service is provided on board ship for the benefit of the passengers.

Another interesting possibility is the application of television to the marine beacon service, demonstrations having been given of a system whereby the actual name of the beacon station is seen on the screen of the television receiver, the bearing of the station also being indicated by this visual means. These experiments were put in hand in order to explore the possibility of extending the direction finding service even to those small vessels where no person is carried with the necessary knowledge of the Morse code which is at present required for the identification of the station.

Finally, the Marconi Marine Company have an organisation, known as the British Wireless Marine Service, which provides a world-wide operating and maintenance service. By means of this organisation, it is possible for the captain of a British ship always to be certain that the wireless equipment—so vital for safety of life at sea, navigation, and the normal requirements of the marine service—will be maintained in an efficient state and manned by competent operators through an extensive organisation of depots in the main shipping centres of the world.

In aircraft services, also, too much stress cannot be placed on the importance of efficient maintenance, but where this is effectively carried out, figures show that virtually 100 per cent. efficiency can nowadays be expected from aircraft wireless of suitable modern design.

I wish to express my acknowledgment and thanks to the Technical General Manager (Mr. C. E. Rickard), to Mr. T. L. Eckersley, and to my colleagues in the Marconi Company for their valued assistance in the preparation of this paper, and to Flight Lieut. W. A. Duncan for his help in connection with the subject of the Control of Wireless for Aviation.

Discussion

Mr. Roderick Denman (*Associate Fellow*): The lecturer had dealt most admirably and comprehensively with a somewhat complicated subject. It seemed as though he had covered the whole field, and that if in the future one desired to read what was the state of aeronautical radio communication in 1935, one could not do better than refer to Captain Furnival's paper.

Further, the paper acted as a timely reminder that safety first in the air was very largely a matter of wireless first, and it would be well to place it on record that this necessity for ensuring safety by proper wireless equipment was utterly inconsistent with the policy of running things on the cheap—a policy which, for reasons with which most people sympathised, had been rather imposed upon the industry in its early stages. The air lines had tried to run services with no wireless operators, no assistant pilot, inadequate ground services, and so on. But one hoped that that era was drawing to a close; and especially was that true of the habit, which apparently was special to this country alone, of failing to take due precautions in respect of the 48 miniature spark transmitters

which would be found to have been incorporated in the design of a typical modern air liner. Spark transmitters were a very potent source of interference; in the case of ground stations they had been forbidden by an international convention as from January 1st, 1936, and it did seem a little unreasonable to imagine that one could put a decent modern receiver into an aeroplane and get proper results from it if there were little or no protection from those 48 sparking plugs. Now that we were being forced to have recourse to ultra-short waves for our approach and landing systems, the matter was clearly coming to a head, and Captain Furnival had quite properly drawn attention to the possibilities of lessening the cost of individual screening installations by making them general.

The paper described one trouble which was becoming prominent as the speeds of aircraft increased, namely, the tendency of the trailing aerial to bend back, and therefore to lose effective height. Mr. Denman asked whether in this country there had appeared any signs of " rain and snow static," a trouble which was regarded very seriously in America, and which was caused by charged particles of rain or snow hitting the aerial. Although it was somewhat infrequent, it appeared that the effects were very grave, because it was reported that, after passing through rain or snow for four or five minutes, a receiver would be completely inactive or blocked out for a period of anything up to 15 or 20 minutes. If we had not experienced that trouble in this country up to the present, we must expect it to show up as our speeds increased. The effect had only been noted on medium waves.

With regard to Captain Furnival's suggestion as to the possibility of using aircraft direction finders on intermediate wave lengths, below 200 metres, Mr. Denman pointed out that apart from reflection from the ionosphere, there was also the question of the reflection from mountains. There were reports from America to the effect that on the intermediate wave lengths the errors that might arise as the result of reflections from mountains might easily amount to ± 22 deg. at a distance of from 20 to 30 miles from a ground station. On medium wave lengths of about 900 metres, at the same distance from the ground station, the error would not be more than ± 7 to 10 deg. He suggested that in Figs. 3A, 3B and 3C, Captain Furnival might indicate the wave lengths and the time at which the curves were taken; such curves were of permanent interest and the addition of the information suggested would enhance their value as records.

With regard to landing systems, there was the so-called United States Army method, which was essentially a homing system, and there was also the equi-signal track beacon. It was thought by the engineers of the United States Bureau of Air Commerce—and Mr. Denman concurred with this view—that a combination of an omni-directional transmission with the directed beacon transmission, and a combination in the aircraft of a radio compass with the device for showing lateral displacement relative to a fixed equi-signal line, would simplify the pilot's task in approaching along this line. If a track beacon alone were employed, it would be found that it was necessary to fly for an average period of 8 to 10 minutes in order to establish the correct final approach to the aerodrome, but by taking the heading of the aircraft relative to the equi-signal line it would be possible to establish very quickly the angle of drift due to the wind. Having ascertained that, one could determine the proper setting of the directional gyro with more speed and facility. He believed that this technique would show a pronounced saving of time and fuel.

Squadron Leader D. DE BURGH: His remarks were likely to be influenced by the fact that for the last five years he had been in India, where he was more concerned with the Empire routes than with local routes. Referring to the use of radio telegraphy versus telephony, he said that he had been called in, in an advisory capacity, to investigate a good deal of trouble that had been experienced on communications in India, and it was his considered opinion that

telegraphy was about the only satisfactory means of communication to aircraft when working under difficult conditions, particularly in the tropics. When using telegraphy it was essential to employ a first class full-time operator. A good many of the troubles that had arisen had been due to the employment of part-time operators; it was only when conditions were bad and when communication was most needed that the importance of employing fully experienced men really showed up.

Discussing the screening of installations (and he recalled Mr. Denman's reference to interference from sparking plugs) Squadron Leader de Burgh mentioned a recent experience with an aircraft fitted with a short wave Marconi installation, 37*a*, 38*a*, on his recommendation. The installation was excellent ordinarily, but in this particular case it was entirely ruined as the result of inadequate screening, and he urged that it was time all installations on aircraft were fully screened.

A fact that he had noted as the result of working on short waves with aircraft was that not only could one use a shorter wave length in the air than on the ground, but also it was apparent that one could use a shorter wave length air to ground than from ground to air. The evidence on that matter was small, but there was a tendency that way and he asked for Captain Furnival's views.

With regard to the rather universal use of the wave band round about 45 metres, he said it had been found in connection with the cross-India routes that it was all very well under good conditions, but under bad conditions the wave band round about 45 metres gave trouble, particularly when there was fading. It occurred within about 300 miles of the station with which the aircraft was working. He was rather inclined to think that it would be a good thing under those circumstances, when there was bad fading, to drop to about the 20-metre band, and work via a distant station, linking back from that to the station with which the aircraft was concerned. By so doing one might also simplify the installation, in that it might enable a more limited wave band to be employed on the aircraft.

In a comment on direction finding, and Captain Furnival's reference to the system of employing a rotating loop on the aircraft, he said that in the old systems—and he referred particularly to the rotating coil of the Robinson type—trouble had been experienced with variable quadrantal error, but he presumed that this would remain fairly constant with all-metal aircraft. He asked Captain Furnival to confirm this point.

Mr. W. O. Manning (*Fellow*): With reference to Fig. 11, he said it showed the nose of an aeroplane having in one place a Venturi tube mounted on a triangular bracket, a pitot tube mounted on another triangular bracket of rather more elaborate type, and another instrument which he could not quite recognise; there were also two separate large wind-driven generators, and apparently a mast and flag. He could quite understand that under those conditions it did not matter very much if one added a separate loop aerial. But he would like Captain Furnival to believe that on the very much faster machines of the future the presence of a loop aerial of that type would be a very serious matter indeed, for it would reduce the speed of the machine considerably. If aerials of that type were to be necessary for aerial navigation, and if they could not be made to function inside the metal fuselage, we should have to make the fuselage of some other material; that indicated his opinion of the importance of wireless communication. He asked to what extent a fuselage could be made of metal if it were to carry an aerial of that type inside. If, for example, a machine had a metal framework covered by some non-metallic substance, would such an aerial work under those conditions? Possibly—he did not speak as a wireless expert—if the rear part of the fuselage were made of metal, the front part of the fuselage could be made of something else and the aerial could be placed there.

Mr. Manning's particular concern, however, was to ask whether anything more could be done in connection with the wireless equipment to reduce the obstruction to the aircraft.

Flight Lieut. W. A. DUNCAN: With reference to the shortage of frequency channels for aeronautical wireless, he said that many of the difficulties encountered at the present moment were due to that cause, and he could not see immediately how the situation was to be improved.

The aeronautical services were being squeezed on the one side by broadcasting, which was continually expanding, and on the other by the marine services which did not feel able to make further concessions. Largely to avoid frequency troubles, aviation had recently had recourse to the employment of ultra-short waves. No sooner had this been done, than it became apparent that large portions of the band below 10 metres would be claimed by television.

The problem might have serious effects on the development of aviation, which depended to a great extent on wireless for the regularity and safety of its services.

Mr. NIGEL NORMAN (*Fellow*): He associated himself with Mr. Denman's remarks concerning the remarkable scope of the paper, which was informative even to those who were not technically instructed.

Referring to airport installations, the lecturer had mentioned remote operation of transmitting stations and also of directional receiving. He asked if Captain Furnival could give any indication of the maximum distance at which an Adcock direction finding station could be operated without any great loss of accuracy or sensitivity. Another question was whether there were likely to be any aerial installations on control towers in the future; there seemed various indications that they might be required, particularly in connection with the ultra-short waves, and if so provision would no doubt have to be made for them in the design of the building.

With regard to approach systems, was it regarded as possible at present to couple the radio guiding system directly with the directional control of the aircraft in order to simplify the duties of the pilot, which were becoming more and more complex? It would seem that when a machine was within close range of the airport it might be possible to couple with the radio guiding system the directional controls, perhaps the rudder at any rate, and so relieve the pilot of the responsibility for direction while making a blind landing.

No opportunity should be lost of stressing the importance of providing a supply of suitable operators. He gathered that it was difficult to secure suitably trained experienced operators, and suggestions from Captain Furnival would be valuable as to the way in which a satisfactory supply could be maintained to meet the demand of expanding air services during the next few years.

Mr. W. BOND: Whereas Captain Furnival, in his description of the blind landing system, seemed to be doubtful of the reliability of guidance in the vertical plane, his own experience showed that in actual practice the guidance in the vertical plane was quite satisfactory.

As he understood it, there was a transmitter with very close voltage regulation on the incoming power and an amplifier with automatic gain control, thus ensuring a constant power output to 1 or 2 per cent. The radiated field pattern should therefore remain constant from day to day. There was no evidence whatsoever that atmospheric conditions had any effect on the field patterns; so that there remained the effect of the varying conductivity of the ground, and experience had again shown that this was very small. A large amount of information was available, collected over a number of years, on these variations, and it was possible to plot a large number of glide paths formed by lines of equal field strength and to select upper and lower limits on the curves between

which it was always possible to make a safe glide to the airport under all conditions of weather and wind.

It was comparatively simple, when one was provided with all the available information, to design a blind landing runway that was 100 per cent. safe. A matter, however, which had an appreciable effect on the glide path was the reflecting effect of large metal objects close to the aerials. That was the usual source of trouble if there were any distortion on the glide path. At Le Bourget it had been decided that the aerial must be placed at a definite spot; that was about 80 yards from a large hangar, and the result was that the path was considerably distorted. The remedy was, of course, obvious. The beauty of the Lorenz system was that the glide path was not dependent, as in the American system, on the absolute value of the field and the sensitivity of the receiver remaining constant from day to day, but merely on the sensitivity of the receiver and the field remaining constant during the few seconds of descent.

The Lorenz system was developed initially for the German Air Ministry and it was one of their essential requirements that the approach should be possible from both directions and that the dot and dash zones should be as broad as possible in order that the pilot should find the equi-signal path easily. A large amount of information had already been published on the radiation from dipoles, and he felt confident that there was no difficulty in designing an aerial system to meet any given set of requirements.

Mr. Bond expressed complete agreement with Captain Furnival regarding the necessity for complete screening. The problem was well understood; all that was required was that it should be put into practice in this country. In that connection it was his experience that the figures in the cockpit of a quiet aircraft should not exceed 2 microvolts per metre, while the maximum tolerable in a bad aircraft would be 5 microvolts per metre.

Mr. J. A. Smale: He would like to emphasise the absence of information in the paper on the problem of communication between aeronautical stations, though that consideration of this question might very well answer the references to insufficiency of wave lengths. In Fig. 14 there was shown a wonderful network of beacons near the various towns in Great Britain, and he had no doubt that it was the intention of the authorities to provide wireless communication also between the air stations at all those places. But that seemed most unreasonable and wasteful, because the British Post Office had a very good network of lines between those places, and upon those lines all the traffic between aeronautical stations could be handled. The same applied over the whole world; the very efficient communication system of cables and wireless throughout the world would provide instantaneous communication between the various aeronautical stations. One could send a message to New York and receive a reply in 45 seconds; surely that should be good enough! Presumably there was a very good reason why the matter had not been dealt with in the paper; probably the equipment for direct inter-aeronautical-station work was of much greater magnitude than that for communication with the aircraft itself.

Mr. W. J. Clennell: Would it be possible to place a direction finding aerial inside the rudder, because the rudder would normally point in the direction of the required destination, and conceal the hitherto exposed position of the direction finding aerial?

Mr. E. R. Hatchett: Could Captain Furnival explain why this country lagged so much behind others in the application of wireless to aircraft? He believed that in America there was no trouble with regard to bonding and screening. It was his own experience that aircraft arriving from the Continent, especially from Germany, using short wave landing apparatus, were extremely well bonded and screened. It seemed, in view of the years of experiments, that

it was nearly time that we brought our aircraft installations up to the standard of those of other countries.

As one associated with an aircraft operating company, Mr. Hatchett said that the standard of efficiency all round had increased greatly recently. Operators had to qualify through the Air Ministry, and the standard of efficiency required by the Air Ministry was equivalent, he believed, to that required by foreign countries.

The CHAIRMAN (Mr. H. E. Wimperis): The possible use of micro waves for detecting other aircraft in the air at the same time was a very alluring topic, and he asked Captain Furnival by what method he would propose that micro waves could be used in order to achieve that very useful purpose. One assumed that, whatever the method, it would work by day or by night, in clear weather or in fog.

With regard to the pulse method of direction finding, which Captain Furnival had illustrated, the Chairman did not quite follow how that method succeeded in singling out the direct pulse and rejecting that which was reflected from the Heaviside layer.

Fig. 13, showing the Marconi-Adcock and Bellini Tosi night effect curves, indicated that by using the Adcock system the frequency of errors of the order of 15 deg. was enormously reduced. But it also indicated that the frequency, whether or not the Adcock system was used, was the same in respect of 3 deg. errors, and in respect of 2 deg. errors—which in his view were large enough—the Adcock method was not quite so good as the Bellini Tosi. Therefore, he wondered whether the curve represented isolated observations and not the mean of several.

With regard to the guiding of aircraft by radio to aerodromes under conditions of poor visibility, the paper provided a very useful record of the position to date; but the Chairman asked if Captain Furnival considered it likely that within the next five years there would be in general use an effective radio system for landing passenger-carrying machines under conditions of thick fog.

It had been pointed out that the effect of the increasing speed of aircraft was to make the trailing aerial more horizontal than ever, and that it was electrically inefficient to put the gear inside the framework of the machine, even when it was not covered with a metal skin. Could the aerial of the future be made with something which would no longer interfere with the finer feelings of the aerodynamic experts? At the moment they were sensitive about aerials and would like to put them somewhere where they did not matter. It was very bad to place them near the leading edge of a wing, but if they were near the trailing edge they did not matter so much.

Mr. D. N. SHARMAN (*contributed*): Captain J. M. Furnival's lecture, "Wireless and its Application to Commercial Aviation," with particular reference to the application of ultra-short and micro-wave radiation for approach and blind landing purposes, was extremely interesting.

By the bery kind permission of the Air Ministry, the writer had an experimental subterranean beacon installed on Croydon aerodrome for the projection of ultra-short and micro-wave beam formations.

A preliminary demonstration with a field strength meter was given a short while ago to the Air Ministry officials.

Briefly, his approach and blind landing system depends on a lop-sided or deformed beam formation with a flattened edge by the aid of suitable screening and absorption. Undesired back radiation and other subsidiary beam formations are also eliminated.

This flattened edge, as viewed from above, occurs near the maximum strength of the beam and by two partially superposed deformed beams from

one or two beacons an overlapping area or equi-signal path with approximate parallel sides can be created.

Synchronised " A " and " N " signals are superposed on the two beams in such a way that the line of approach is indicated by a distinct characteristic note.

In elevation, the beams are projected at an angle of 7 to 10 degrees to the horizontal in order to suit the gliding angle of the approaching machines.

With the aid of a descent commencing and a boundary marker beacon the pilot can thus be guided to the aerodrome.

The system also employs micro or infra-red rays for the absolute blind landing of aircraft.

The indication of position to the approaching pilot is of paramount importance. For this purpose a position indicating instrument termed the " distim-glid-altimeter " could be employed with this or any other blind approach and landing system. This meter would indicate to the approaching pilot his distance from the point of landing, his altitude, the time he has at his disposal to reach the aerodrome and whether he is gliding at the correct gliding angle, from the moment of passing the first marker beacon. A hundred feet altitude danger light and a visual homing indicator would be incorporated with this self-contained instrument.

The transmitter has an output of approximately 50 watts, serving a range of 25 miles, and the gear can be used as a mobile unit in order to suit the prevailing wind direction or for use during military manœuvres.

Reply to Discussion

In reply to Mr. Denman, the static disturbance referred to had been observed when flying through rainstorms, etc. The problem of static was being considered in some detail in America in regard to direction finding loops; the make-up of the loop and the actual siting of it on the machine had been the subject of considerable investigation. The latest reports indicated that the best place for the loop was at the back, near the tail.

Discussing the use of intermediate wave lengths for directional services, he said that errors from reflection were liable to occur, of course; an error of 22 deg., such as Mr. Denman had mentioned, in short and intermediate wave lengths, as compared with 7 deg. on medium wave lengths, might perhaps be anticipated. He agreed to indicate, in connection with Figs. 3A, 3B and 3C, the wave lengths used and the times at which the short wave observations were made, for such information would be a useful addition.

The proposal made by Mr. Denman concerning the combination of the radio azimuth with the track beacon was of interest and lined up to some extent with the Marconi Company's views on the subject.

Commenting on Squadron Leader de Burgh's remarks concerning telegraphy versus telephony, he said that, given a good operator and a good telegraphic service, there was no doubt at all as to which was preferable under tropical or other bad conditions.

Apparently everyone felt that full screening was necessary; the time had come when full screening must be used as a standard fitting, and it was impossible to secure the required degree of selectivity and sensitivity unless the interference noises were suppressed.

He had heard that, particularly in India, the 45-metre wave did not at times suffice, for the reasons given by Squadron Leader de Burgh, and also because of

the fact that it was not so free from atmospheric disturbances as were the shorter wave lengths; so that it would appear that a shorter wave length might be used with advantage.

As to the suggestion to skip one section of a route and to communicate with a remote station and then back again to the station with which the aircraft was immediately concerned, that appeared to be a matter of organisation rather than of technique.

As to the different effect observed when transmitting from air to ground and from ground to air; at first sight one would imagine that the conditions would probably be the same.

The amount of error liable to occur with the loop direction finder would be dependent to a very great extent on the design of the installation and the siting of the loop in relation to the masses of the metal on the machine. In the case of the machine shown in Fig. 11, the loop was well forward and no appreciable amount of error was observed.

The problem with regard to the drag induced by the loop had been appreciated, and undoubtedly the drag would be diminished, if not extinguished altogether, if the aircraft constructor and the engine manufacturer would screen the engine completely, because more sensitive receivers could be fitted and the size of the loop could be reduced in consequence.

To place the loop inside the fuselage completely covered with metal would, of course, defeat the object of the loop. If the fuselage were composed partly of metal, *i.e.*, having metal frame and a covering of fabric, the effect of the metal frame would vary according to the amount of metal in it. But even with the larger size of loop, comparable with that shown in Fig. 11, the amount of drag it would induce would depend on its position on the machine. With the loop in the fore-and-aft direction, the drag would not be so serious. It was also possible to design the loop to be retracted within the hull of a flying boat or the fuselage of an aeroplane when not required for use.

With reference to the remarks made by Mr. W. A. Duncan, Captain Furnival supported heartily the objections to the scarcity of wave lengths available, and said that there was not the slightest doubt that if more wave lengths were available, much more could be done, and done quickly.

Replying to Mr. Nigel Norman, Captain Furnival said that he could not give a definite answer to the question concerning the distance over which it was possible to control an Adcock station, because the matter was in development at the present time.

The problem of the amount of wireless equipment required on the control tower was rather important. The landing beam equipment or approach beacon could certainly be placed away from the control tower and controlled through underground cable. All it would be necessary to provide in the control tower would be a small switch panel. It was not possible to place an Adcock system, of course, on a control tower, but in certain cases it might be useful to instal some form of loop direction finder for local services.

With regard to the possibility of coupling the radio guiding system with the directional control of the aircraft, there had been already some investigation of the problem of coupling a wireless directional system to the automatic pilot, and it was still under consideration. Obviously, a good deal of delving and a considerable amount of trial would be necessary before the adequacy or otherwise of such a combination could be pronounced upon.

The need for provision for the training of operators had been foreseen already; the Marconi Company had a training school for aircraft technicians and a certain number of operators. It was realised that training in the particular requirements of aircraft technique was a matter which must be taken in hand

and developed in order that there might be a sufficient supply of trained engineers and operators for future requirements.

Replying to Mr. Bond, Captain Furnival stated that the remarks made concerning the reliability of the track beacon were of considerable interest, but he did not think it was possible at the moment to go further into details in regard to the consistency and adequacy of the vertical guidance from the point of view of guaranteeing a service.

The omission from the paper of any reference to communication between aeronautical stations, referred to by Mr. Smale, was due to the fact that the subject was so large that it would provide sufficient scope for a separate paper.

Replying to the Chairman, he said that one searched about for aids that employed frequencies which, in the first place, were fundamentally suitable in themselves, and which, in the second place, were free for use. Hence, as the very short wave lengths required small apparatus and because they could be arranged to send out very highly directive transmissions, they might be used for the purpose of giving warning of the presence of other aircraft, and so far as one could see, they should function in that respect by day or by night, in clear weather or in fog.

In regard to the pulse sending method, the discrimination of the direct ray from the reflected ray was effected visually through a cathode ray tube.

The night error curves in Fig. 13 were a simultaneous record of night bearings, observed at Chelmsford, of the Kalunburg broadcasting station, transmitting on a wave length of 1,262 metres, during the period from 21.10 to 22.50 G.M.T. (the hour of sunset being 21.32 G.M.T.).

With regard to the general use of a system of guidance into aerodromes which would be effective in conditions of thick fog, he said that, naturally we must feel our way, and he did not think it was within his competence to answer this question, for the reason that he was a wireless engineer and clearly the problem was one affecting both flying and wireless, and the technique which must be developed to enable such a service to be performed must be a combination of the two functions.

Replying to Mr. Hatchett, as to the suggestion that in this country we were behind the times in the application of wireless to aircraft, he said that that depended on the requirements of the aircraft services as to which was to be developed first. One must take into consideration the whole field of demand and supply—short wave and medium wave services, homing, landing beam equipment, and so forth. Certainly, with well screened engines and bonded aircraft, improvements could be effected more quickly than they had been effected in the past.

Finally, dealing with the suggestion to instal an aerial in the rudder, he said that presumably Mr. Clennell was making the enquiry in regard to a directional aerial. The actual position of the aerial for homing must be athwartships, not fore-and-aft.

COMMUNICATED

The problem of aerials, raised by Mr. Wimperis, is divisible into two parts, viz., aerials required for transmission and those used for reception. In regard to the former, the size thereof is a function of the wave length. Where medium waves are employed, there does not seem any immediate alternative to the well-known trailing aerial system, except perhaps on very large aircraft.

When shorter waves are used, it is possible to instal a useful fixed aerial on medium and large size craft, comprising a single wire running from a forward

kingpost to the tail fin. Such an aerial should comply reasonably well with aerodynamical requirements.

In regard to aerials for reception, an important factor was the electrical noise level of the machine. With efficient screening, this is cut down to a low value and enables much more sensitive receivers to be used, thereby permitting a reduction in the size of the aerial system.

Regarding the system described in the communication received from Mr. D. N. Sharman, this is a particular type of landing beam, the general principles of which are covered in the paper.

SOME NOTES ON AIRCRAFT POSSIBILITIES

BY

Captain F. S. BARNWELL, B.Sc., O.B.E., A.F.C., F.R.Ae.S.

(A Lecture read before the Bristol Branch on October 15th, 1935.)

These notes are an attempt to examine what may be achieved in the way of performance, with existing materials and knowledge of aerodynamic engineering.

No claim is made for novelty, either in the data used or in the methods of working from such data to obtain the results arrived at.

Only the simplest engineering mathematics are employed so these results cannot claim academic accuracy, in fact they are most probably considerably inaccurate. But though inaccurate absolutely, the results should be accurate enough relatively for comparative purposes.

Full details of the methods employed are given in the various Appendices. This appears advisable, as it should make quite clear how the results are obtained and leaves it open for anyone to work out further examples by the same methods or to modify the methods themselves.

In view of the doubtful accuracy of the results it may seem rather ludicrous to give results to so many figures; but this is done to ensure percentage accuracy for comparing factors of small relative total value such as slipstream increment; for this reason it would appear justified, though it made the work of preparing these notes considerably more laborious.

The examination is limited to the aeroplane type of aircraft, because it would appear from basic principles that this will always remain the fastest type, and it is assumed that speed is the outstanding superiority of aircraft over other forms of transport.

Aeroplane

The basic feature of the aeroplane is the wing surface. As these notes are primarily concerned with the possible speeds of aeroplanes, attention is confined to the monoplane form of wing surface and at that, to the internally braced, rigid-skinned type.

It must not be inferred from this that the monoplane is labelled as better than the biplane. Each type claims its peculiar advantages. Should controllability, manœuvrability and small over-all size be of primary importance, the biplane is then better than the monoplane. For the same minimum speed the percentage structural weight of the biplane is lower than that of the monoplane, hence its percentage of useful load is higher.

If, however, top speed and rate of climb be the primary requisites, the monoplane then holds a definite superiority.

Wing

In Fig. 1 is shown a monoplane wing of elliptic plan form, of aspect ratio 7 to 1, with a maximum thickness-to-chord ratio of 15 per cent. Elliptic plan form is chosen because this form is the aerodynamic ideal. Aspect ratio of 7 to 1 and maximum thickness-to-chord ratio of 15 per cent. are chosen as affording a good compromise between aerodynamic efficiency and structural weight. The

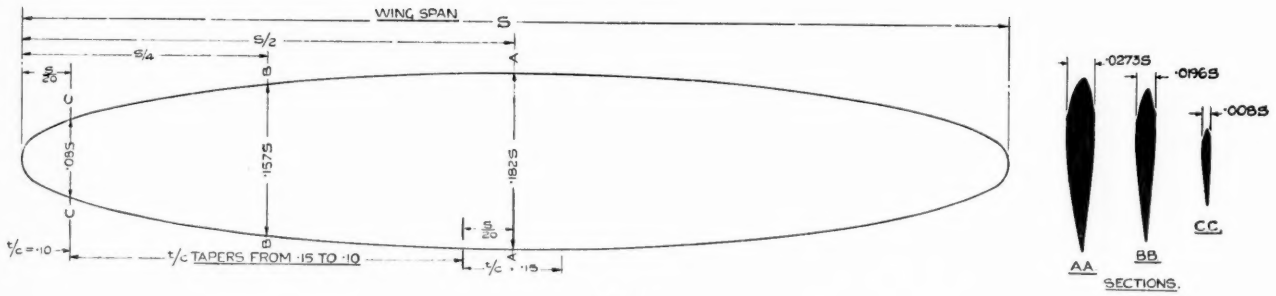


FIG. 1.

Wing of elliptical plan form and of aspect ratio 7/1 (i.e., "mean" wing chord $C_M = S/7$).

Wing area, $A = S^2/7$ or $S = \sqrt{(7A)}$.

Skin area of wing $\doteq 2.07\,A$. Taken as $= 2\,A$.

Wing loading $= W/A$ lbs. per sq. foot.

Power loading $= W$/b.h.p. lbs. per brake horse-power.

Induced drag $D_i = (2/\pi)\,(L/S)^2\,(1/\rho v^2)$. Hence $D_i = (1/11)\,(W^2/A)\,(1/\rho v^2)$ for $L = W$ and for aspect ratio 7/1.

Profile drag $D_P = (2K_F + K_T)\,A\rho v^2$.

Profile drag = "skin friction" drag + "turbulence" drag.

Minimum value for $K_F = 0.0015$ (plate glass).

Minimum possible wing drag $= D_i + (0.003\,A\rho v^2)$.

higher the aspect ratio the higher the aerodynamic efficiency of the wing, but the higher is the structural weight for the same area and strength. The lower the thickness-to-chord ratio the higher the aerodynamic efficiency, but the higher the structural weight for the same strength. In any case the aerodynamic gains for a higher aspect ratio and/or for a lower thickness-to-chord ratio than those here chosen, would be comparatively small.

With this particular plan form, thus decided upon, the wing area A is equal to $S^2/7$ where S is the wing span. It should be made clear that the term wing area is used here (and throughout these notes) in its commonly accepted sense, that is, wing area means projected area of wing in plan. The area of the external skin surface of wing is, of course, rather more than twice the wing area because the wing has an upper surface, a lower surface and some thickness; but for the purposes of these notes it is sufficiently accurate to take the skin surface area of the wing as equal to twice the wing area.

Flying Wing

To consider now the speeds possible for a flying wing. An ideal power plant is assumed which causes no drag and has a propulsive efficiency of 100 per cent. The thrust given by this ideal power plant will be:—

$$T = 550 \text{ b.h.p.}/v$$

T being thrust in lbs., b.h.p. being brake horse-power developed by power plant, v being air speed of flight in feet per second.

A further assumption must be made, namely, that the C.G. of this flying wing is coincident with its centre of pressure and lies on the line of thrust.

For steady horizontal flight under the foregoing conditions, the wing lift L must be equal to the weight W and the total drag must be equal to the thrust T. Three variables may be considered:—

(1) Wing loading, W/A, in lbs. per square foot of wing area.
(2) Power loading, W/b.h.p., in lbs. per brake horse-power.
(3) Air density, ρ, in mass lbs. per cubic foot; which value decreases with height above ground level.

Wing Drag

The drag of a wing is usually considered as the sum of the induced drag, D_i, and the profile drag, D_p.

Induced Drag

The induced drag, $D_i = (2/\pi)\ (L/S)^2\ (1/\rho v^2)$. Where L is the lift in lbs., S is the wing span in feet, ρ is the air density in mass lbs. per cubic foot, and v is the air speed in feet per second.

For the particular case of this flying wing, where lift is equal to weight and aspect ratio is 7, it follows that:—

$$\text{Induced drag, } D_i = (1/11)\ (W^2/A)\ (1/\rho v^2) \text{ lbs.}$$

This is "text-book" aerodynamics, so neither explanation nor proof is called for in these notes. It should be remarked, however, that induced drag is drag which is necessary to give lift; or, perhaps more correctly, drag which is necessarily incurred to produce a force at right angles to the direction of flight.

Profile Drag

The profile drag of a wing may be considered as made up of two parts, skin friction drag and turbulence drag. Skin friction drag is unavoidable because there must be friction between any surface however smooth and the air flowing over it. Turbulence drag (drag due to bad shape or to discontinuous shape)

should be avoidable with a perfectly shaped wing at an angle of attack not greater than, say, 6° above zero lift attitude.

The lowest value which has been measured for skin friction drag is that over the surface of polished plate glass and is about 0.0015 ρv^2 lbs. per square foot of skin surface area.

For the purpose of these notes it is assumed that 0.0015 ρv^2 lbs. per square foot of skin surface area is the lowest possible skin friction drag, and this value is, from now on, referred to as optimum frictional drag and is specified by this term (see Appendix No. 1).

Assuming then that for a perfect wing there is no turbulence drag, that the profile drag consists therefore of skin friction drag alone and at that of optimum frictional drag only, the drag of this perfect flying wing consists of its induced drag, D_i, plus 0.003 $A\rho v^2$.

The equation for speed is therefore:—

$$(1/11)\ (W^2/A)\ (1/\rho v^2) + 0.003\ A\rho v^2 = 550\ \text{b.h.p.}/v.$$

Speed on Wing Loading

The full line curve of Fig. 2 gives the speed at ground level for this perfect

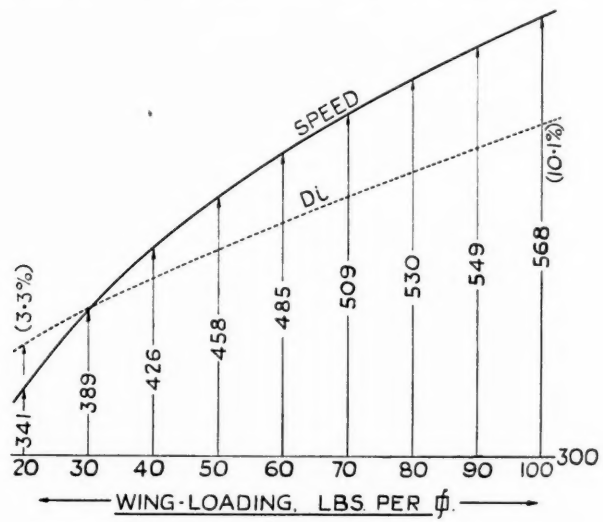


FIG. 2.

Flying wing.

Speed (m.p.h.), at G.L., on wing loading.
Power loading constant at 12lbs. per b.h.p.
$E = 100$ per cent. so $T = 550$ b.h.p./v.
$W^2/0.0021725\ v + 0.00008532\ v^3 = 550\ W$.

flying wing at a constant power loading of 12lbs. per b.h.p. In this case the equation for speed becomes

$$W^2/0.0021725\ v + 0.00008532\ v^3 = 550\ W,$$

W being for this case the wing loading in lbs. per square foot, and v the speed in feet per second (see Appendix No. 2).

The speed rises from 341 m.p.h. for a wing loading of 20lbs. per square foot to 568 m.p.h. for a wing loading of 100lbs. per square foot.

Speed on Power Loading

The full line curve of Fig. 3 gives the speed at ground level at a constant wing loading of 30lbs. per square foot of wing area. In this case the equation for speed becomes

$$34{,}500/v + (0.0711/10^4)\ v^3 = 16{,}500/\text{power loading (see Appendix No. 3).}$$

The speed decreases from 526 m.p.h. for a power loading of 5lbs. per b.h.p. to 358 m.p.h. for a power loading of 15lbs. per b.h.p.

Speed on Altitude

The full line curve of Fig. 4 gives the speed at a constant wing loading of 30lbs. per square foot and at a constant power loading of 12lbs. per b.h.p. In this case the equation for speed becomes

$$81.82/\rho v + 0.003\ \rho v^3 = 1{,}375 \text{ (see Appendix No. 4).}$$

The speed increases from 389 m.p.h. at ground level (where $\rho = 0.00237$) to 696 m.p.h. at 50,000ft. (where $\rho = 0.000361$).

Induced Drag Percentage

The dotted line curves on Figs. 2, 3 and 4 give value for induced drag expressed as a percentage of the total drag. On Fig. 2 the induced drag rises from about 3.3 per cent. (at 20lbs. wing loading) to about 10.1 per cent. (at 100lbs. wing loading). On Fig. 3 the induced drag rises from about 1.35 per cent. (at 5lbs. per b.h.p.) to about 6 per cent. (at 15lbs. per b.h.p.). On Fig. 4 the induced drag rises from about 4.4 per cent. (at ground level) to about 16 per cent. (at 50,000 feet).

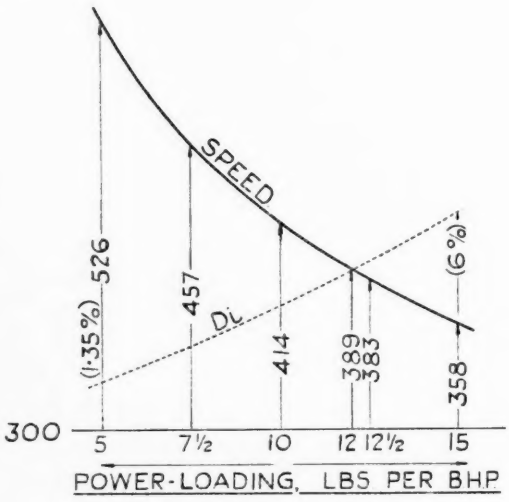


FIG. 3.

Flying wing.

Speed (m.p.h.), at G.L., on power loading.
Wing loading constant at 30lbs. per b.h.p.
$E = 100$ per cent.
$34{,}500/v + (0.0711/10^4)\ v^3 = 16{,}500/$ power loading.

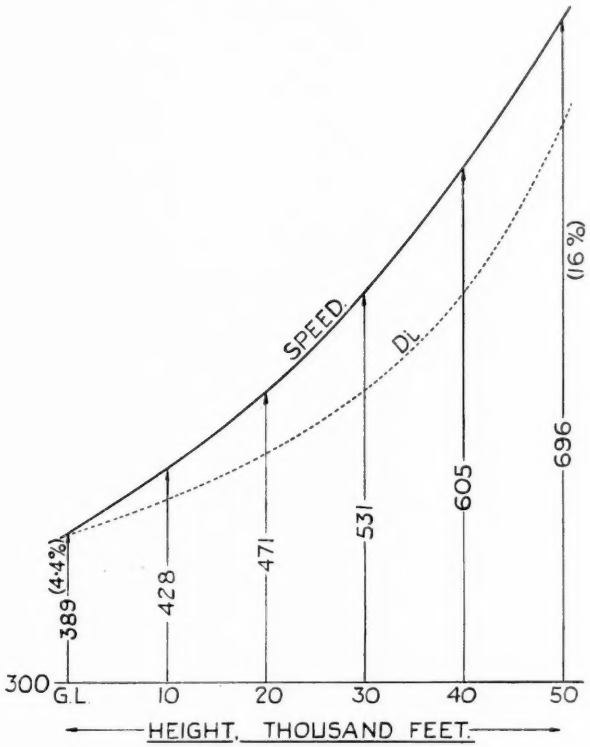


FIG. 4.
Flying wing.

Speed (m.p.h.) on altitude.
Wing loading constant at 30lbs. per b.h.p.
Power load constant at 12lbs. per b.h.p.
$E = 100$ per cent.
$81.82/\rho v + 0.003\ \rho v^3 = 1,375$.

Conditions for High Speed

The curves of Figs. 2, 3 and 4 indicate the advantages of high wing loading, of low power loading and of high altitude, in attaining high speed.

As a reductio ad absurdum one might note that if this perfect flying wing with its ideal power plant were 100lbs. per square foot wing loading, and of 5lbs. per b.h.p. power loading, its speed at 50,000 feet ought to be 1,420 m.p.h. But were this wing of, say, 20ft. span, hence of about 44in. maximum chord length and of about 6½in. maximum thickness, a power plant developing 1,140 b.h.p. would have to be stowed inside it (see Appendix No. 5).

Again, 1,420 m.p.h. is about twice the speed of sound in air; at speeds over about 500 m.p.h. compressibility effects are incurred, tending to increase drag and to decrease lift; so the data, giving this 1,420 m.p.h., have become quite inaccurate.

Stabilised Flying Wing

A wing of high aerodynamic efficiency is unstable by itself. To give stability a certain amount of tail surface and of fin surface must be added, and these surfaces must be located at a sufficient distance behind the wing.

In Fig. 5 is shown the flying wing stabilised by the addition of a tail and a fin. The sizes given for these stabilising surfaces and their locations with respect to the wing are about correct to give stability in high speed flight with the location assumed for the C.G., namely, at 0.3 of the mean chord length aft of the leading edge of this mean chord. The body shown here, for attaching tail and fin to wing, is of about the minimum cross-sectional size to afford adequate strength and stiffness.

Extra Skin Area

The area of this tail is 16 per cent. of the wing area, the area of this fin is 7 per cent. of the wing area, and the area of the external surface of the body (the skin area of the body) is about 46 per cent. of the wing area. So the total skin area of this stabilised wing is about 2.92 times the wing area, or about 46 per cent. greater than that of wing alone.

Additional Induced Drag for Stabilising

There is a down load on the tail in high speed flight, because the centre of pressure on the wing lies then behind the C.G. The assumed position for C.P. at 0.5 of the mean chord is a reasonable one for high speed flight. As C.G. is at 0.3 of the mean chord, and as centre of pressure on tail lies 2.7 times mean chord aft of the C.G., it follows that the necessary down load (for balance) on the tail is $\{(0.5-0.3)/(2.7-0.2)\}$ W or 0.08 W, whence the lift of the wing, L, must now be equal to 1.08 W.

From the equation for induced drag given previously it follows that as the wing lift is increased by 1.08, the induced drag of the wing must be increased by $(1.08)^2$, *i.e.*, by 1.166 or by 16.6 per cent. It also follows that as lift on tail is 0.08 W and span of tail is 0.30 span of wing, induced drag of tail must be equal to $[0.08/0.3]^2$, or 7.1 per cent. of that of the wing alone.

Total Extra Drag for Stabilising

Hence, for this stabilised wing the induced drag is 23.7 per cent. higher than that of wing alone (flying wing) and the skin friction drag 46 per cent. higher, assuming again no turbulence, optimum frictional drag, and also that there be no drag due to interference.

Interference

Interference is a factor which can be avoided wholly, or in large part, by careful design. A so-called streamline body is subjected only to skin friction drag because the air can flow continuously over its surface; this postulates of course that there be no cross-wind force, as such would necessitate also induced drag. But if two streamline bodies be joined together, or placed near to one another in an unhappy manner, the air flow over the one will interfere with that over the other (because these flows desire to travel in different directions) and this results in turbulence with increase of drag as a result.

Speed on Wing Loading

In Fig. 6 is given a curve of speed at ground level, for this stabilised wing, at a constant power loading of 12lbs. per b.h.p. In this case the equation for speed becomes

$$W^2/0.001756\ v + 0.0001246\ v^3 = 550\ W \text{ (see Appendix No. 2).}$$

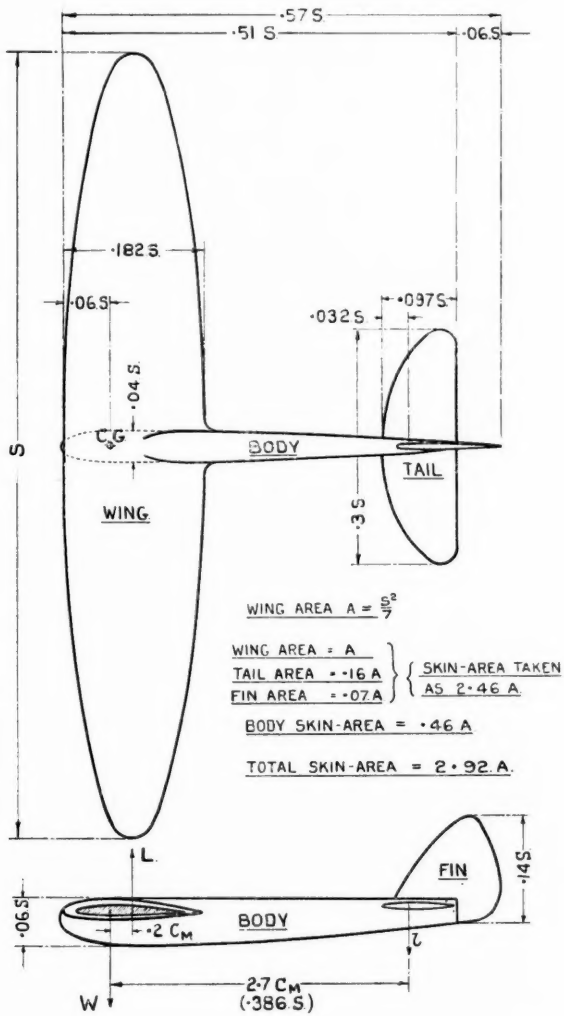


FIG. 5.

Stabilised wing.

C.P. assumed (for high speed flight) as at 0.5 C_M.
C.G. is at 0.3 C_M, *i.e.*, L lies 0.2 C_M aft of C.G.
$l = (0.2/2.5)\ W = 0.08\ W$ so $L = 1.08\ W$.
Induced drag for tail $= (0.08/0.3)^2 = 7.1$ per cent. of original D_i and induced drag of wing is increased as $(1.08)^2$, *i.e.*, by 16.6 per cent.
Hence, due to tail, induced drag of wing alone (D_i) is increased by 23.7 per cent.
Hence, for this case, $D_i = (1.237/11)\ (W^2/A)\ (1/\rho v^2)$
and $D_F = (2.92 \times 0.0015)\ A\rho v^2 = 0.00438\ A\rho v^2$.
$E = 100$ per cent., *i.e.*, $T = 550$ b.h.p./v.

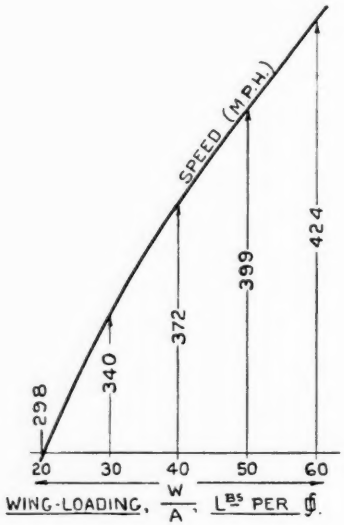


FIG. 6.

Stabilised wing.

Power loading, W/b.h.p., 12lbs. per b.h.p.
Speed (G.L.) on wing loading.
$W^2/0.001756\ v + 0.0001246\ v^3 = 550\ W$.

The speed rises from 298 m.p.h. for a wing loading of 20lbs. per square foot to 424 m.p.h. for a wing loading of 60lbs. per square foot.

Speed on Altitude

In Fig. 7 is given a curve of speed, for the stabilised wing, at a constant wing loading of 30lbs. per square foot and at a constant power loading of 12lbs. per b.h.p. In this case the equation for speed becomes

$$101.2/\rho v + 0.00438\ \rho v^3 = 1{,}375 \text{ (see Appendix No. 4).}$$

The speed increases from 340 m.p.h. at ground level to 462 m.p.h. at 30,000 feet.

This stabilised wing is therefore of about 12½ per cent. lower speed than is the flying wing, in other words, the cost of stabilising has been a loss of about 12½ per cent of speed.

This very definite loss of speed would appear an argument in favour of the tail-less type of aeroplane. But the tail-less type must have a heavy sweep back, considerable wash out, and some form of additional control surfaces at its wing tips. It is unlikely that, for an equal measure of stability and controllability, the induced drag or the skin area of the tail-less type would be less than that of the normally stabilised wing.

The speed curves for the stabilised wing emphasise again the value of high wing loading and of high altitude for high speed flight.

Assumed Limiting Factors

High wing loading is not only of advantage for high speed, it entails also low percentage structure weight.

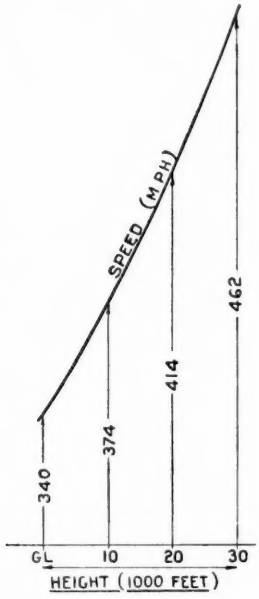


FIG. 7.

Stabilised wing.

$W/A = 30$ lbs./b.h.p.
$W/\text{b.h.p.} = 12$ lbs./b.h.p. } constant.

Speed on height, $101.2/\rho v + 0.00438\ \rho v^3 = 1{,}375$.

High wing loading is an unfortunate term; a better way of expressing the facts would be to say that for an aeroplane of a certain fixed weight the wing area is decreased, rather than that the wing loading is increased, though the latter statement is a necessary corollary from the former; put in this way it becomes obvious why increasing the wing loading tends to increase speed and to decrease percentage structural weight. But wing loading is necessarily limited by considerations of take-off and landing.

Low power loading tends also to give high speed; this is self-evident, for low weight per b.h.p. means high b.h.p. per weight. But the higher the b.h.p. per pound of total weight, the higher must become the percentage power plant weight and the lower, therefore, the useful load percentage.

High altitude is obviously of advantage for high speed because of the reduced parasite drag at reduced air density. By parasite drag is meant, in this case, all the drag except the induced drag; the induced drag increases as air density decreases, but as it is a small percentage of the parasite drag the result of reduction of air density is to increase speed.

But altitude for flight is limited by considerations of passenger comfort; to ensure this it becomes more difficult and more costly in weight, the greater the altitude. Difficulties of maintaining the b.h.p. of the power plant also place restrictions on altitude of flight.

It is assumed from now on:—

(1) That wing loading is 30lbs. per sq. foot.
(2) That power loading is 12lbs. per b.h.p.
(3) That altitude for flight is limited to 10,000ft.

And this because :—

(1) Represents about the limit at which airworthiness landing requirements can be achieved with the best of flaps and brakes.

(1) and (2) together represent about the limit at which airworthiness get-off can be achieved with the best of flaps and of controllable pitch airscrews.

(3) Represents about the limit for passenger comfort, without resource to unusual equipment.

Under these constant conditions, thus arbitrarily decided upon, namely, 30lbs. per sq. foot wing loading, 12lbs. per b.h.p. power loading and a maximum altitude of 10,000 feet, the speed of the flying wing is 389 m.p.h. at ground level and 428 m.p.h. at 10,000 feet, whilst the speed of the stabilised wing is 340 m.p.h. at ground level and 374 m.p.h. at 10,000 feet.

Practical Considerations

An aeroplane of the form of this stabilised wing would, however, have a body relatively too small in cross-section for normal transport purposes, unless perhaps the machine were of very large size.

Again, to attain the correct location for the C.G., it is practically certain that the nose of the body would have to project some considerable distance ahead of the leading edge of the wing.

In Fig. 8 is depicted the stabilised wing with a body of proportions that might be termed practical compared to those of the wing. The skin area of this practical body is 1.02 times the wing area, hence the total skin area has now become 3.48 times the wing area or 74 per cent. greater than skin area of wing alone.

In practical flight, again, an aeroplane must have control surface in addition to, or forming parts of, its wing and its stabilising surfaces. The wing must be broken by ailerons, the tail must be broken up into tail plane and elevators, the fin must be broken up into fin and rudder. These breaks must increase the drag of these surfaces.

Experimental figures indicate that the drag of a wing, with well shrouded Frise balanced aileron, is increased by about $0.00045\ \rho v^2$ lbs. per sq. foot of wing area.

Hence, as drag of wing in way of ailerons is increased by 15 per cent. of optimum frictional drag, and as about one-third of the wing area lies in way of ailerons, it follows that the fitting of ailerons increases the wing drag by 5 per cent. of optimum frictional drag.

Experimental figures indicate again that the drag of tail and elevator and of fin and rudder are both increased by about $0.0006\ \rho v^2$ lbs. per sq. foot, because of the breaks between tail plane and elevator and between fin and rudder.

Hence, it follows that these breaks increase the drag of these surfaces by 20 per cent. of optimum frictional drag.

Finally, it will be noted that an eyebrow has been added to the body, to afford vision for the pilot; such a break of contour would add turbulent drag of amount equal to about 11 per cent. of the optimum frictional drag for this body.

For this stable and controllable aeroplane with practical body and with ideal power plant, of Fig. 8, the induced drag remains at

$$(1.237/11)\ (W^2/A)\ (1/\rho v^2)\ \text{lbs.}$$

The profile drag of the wing is now

$$(1.05 \times 0.0015 \times 2A)\ \rho v^2\ \text{lbs. or } 0.00315\ \rho v^2\ \text{lbs.}$$

The profile drag of the body is now

$$(1.11 \times 1.02A \times 0.0015)\ \rho v^2\ \text{lbs. or } 0.0017\ A\rho v^2\ \text{lbs.}$$

The profile drag of the complete tail unit is now

$$(1.2 \times 0.23 \times 2A \times 0.0015)\ \rho v^2\ \text{lbs. or } 0.00083\ A\rho v^2\ \text{lbs.}$$

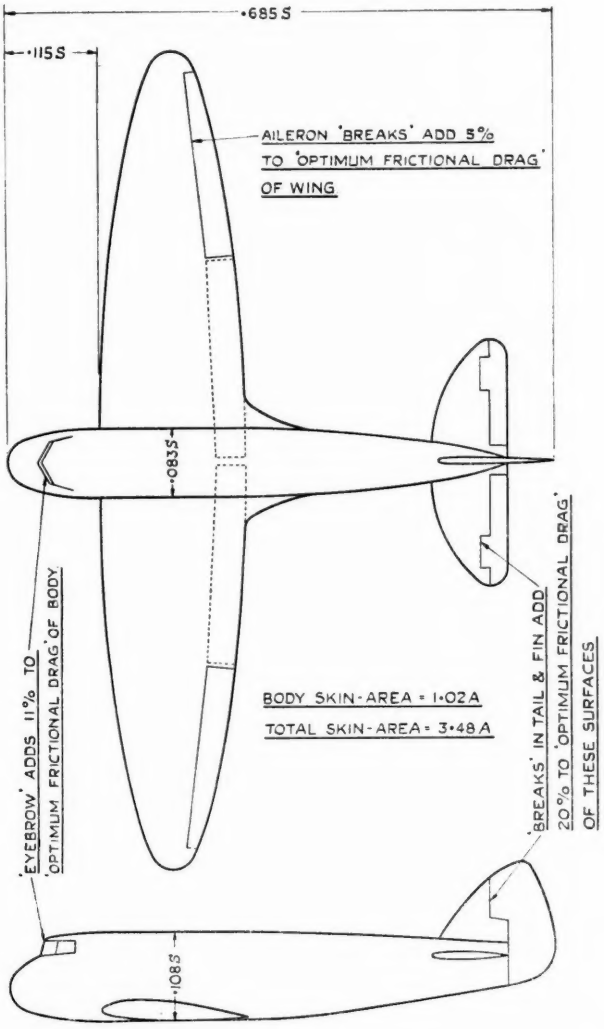


FIG. 8.

Wing loading, W/A, constant at 30lbs. per b.h.p., *i.e.*, $W = 30\ A$.

Power loading, W/b.h.p., constant at 12lbs. per b.h.p., *i.e.*, b.h.p. $= W/12 = 2.5\ A$.

$E = 100$ per cent., so $T = 550$ b.h.p./v, *i.e.*, $T = 1{,}375\ A/v$.

$D_i = (1.237/11)\ (W^2/A)\ (1/\rho v^2) = 101.2\ A\ (1/\rho v^2)$ (as before).

$$D_P = \left\{ \begin{array}{l} \text{Wing } (1.05 \times 2\ A \times 0.0015) = 0.00315\ A \\ \text{Body } (1.11 \times 1.02\ A \times 0.0015) = 0.0017\ A \\ \text{Tail unit } (1.2 \times 0.23 \times 2\ A \times 0.0015) = 0.00083\ A \end{array} \right\} = 0.00568\ A\rho v^2.$$

Equation for speed:— $D_i + D_P = T$.

Speed = 312 m.p.h. at G.L. = 342 m.p.h. at 10,000ft.

(Speed = 299 m.p.h. at G.L. = 329 m.p.h. at 10,000ft., if $E = 90$ per cent.)

It should be noted that the term profile drag is used now in stating parasite drags of wings of body and of tail unit, because the increases of drags occasioned by breaks should be regarded as due to turbulence, not to increase of skin friction.

As wing loading is 30lbs. per sq. foot, power loading 12lbs. per b.h.p. and propulsive efficiency remains at 100 per cent., the equation for speed now becomes:—

$$101.2/\rho v + 0.00568\,\rho v^3 = 1{,}375 \text{ (see Appendix No. 6).}$$

From this is obtained that the speed is 312 m.p.h. at ground level where $\rho = 0.00237$, and 342 m.p.h. at 10,000ft. where $\rho = 0.001756$.

Comparing these with the figures obtained for flying wing and for stabilised wing, it is seen that this stable and controllable wing with practical body is of about 8½ per cent. lower speed than the stabilised wing and of about 20 per cent. lower speed than the flying wing.

For later comparison it should be noted that were the propulsive efficiency only 90 per cent. (instead of the 100 per cent. so far assumed) these speeds would become

299 m.p.h. at ground level,
328.7 m.p.h. at 10,000 feet,
about 9 per cent. lower (see Appendix No. 6).

Further Practical Considerations

But the ideal power plant is unattainable; the airscrew cannot translate 100 per cent. of the b.h.p. given to it into t.h.p. The engine cannot be of 100 per cent. thermal efficiency, so it is practically certain that drag of some amount will be necessitated to carry away the wasted heat; it is also possible that added bodies must be provided to accommodate the engines (as in wing-engined aircraft) or that the body must be increased in size or modified in shape to accommodate the engine.

Airscrew

For a fast aeroplane, having airscrew r.p.m. such as to give a reasonable tip-speed (say not above 900ft. per second) it should be possible to achieve an airscrew efficiency, E, of 90 per cent.; whence airscrew thrust, T, is equal to 495 b.h.p./v lbs., where v is speed, in feet per second.

Civil Transport Aeroplane

In Fig. 9 is depicted the stable and controllable aeroplane with practical body, plus the external additions necessary in order that the power plant may convert its b.h.p. into t.h.p.

Fig. 9 (*a*), as depicted in full lines, shows a normal case of twin tractor airscrews driven by engines contained in nacelles which are mounted on the wing.

Fig. 9 (*b*), as depicted in dotted lines, shows the case of twin pusher airscrews and, in this case, it is assumed that the power plant causes no external additions other than the airscrews themselves with their shaft casings and fairing tails.

A definite size (59ft. 2in. wing span) is now given to the machine, hence a definite wing area of 500 sq. ft., a definite weight of 15,000lbs. and a definite b.h.p. of 1,250. But the over-all proportions remain the same; wing loading remains at 30lbs. per sq. foot; power loading remains at 12lbs. per b.h.p.; so performance would remain the same were E to remain 100 per cent. and were there no external additions.

A definite size has been given at this stage because it is convenient to do so when looking into the question of weights; it will also be noted that for this particular size, the proportions fixed upon for the practical body do in fact make it of a practical cross-sectional size for transport purposes.

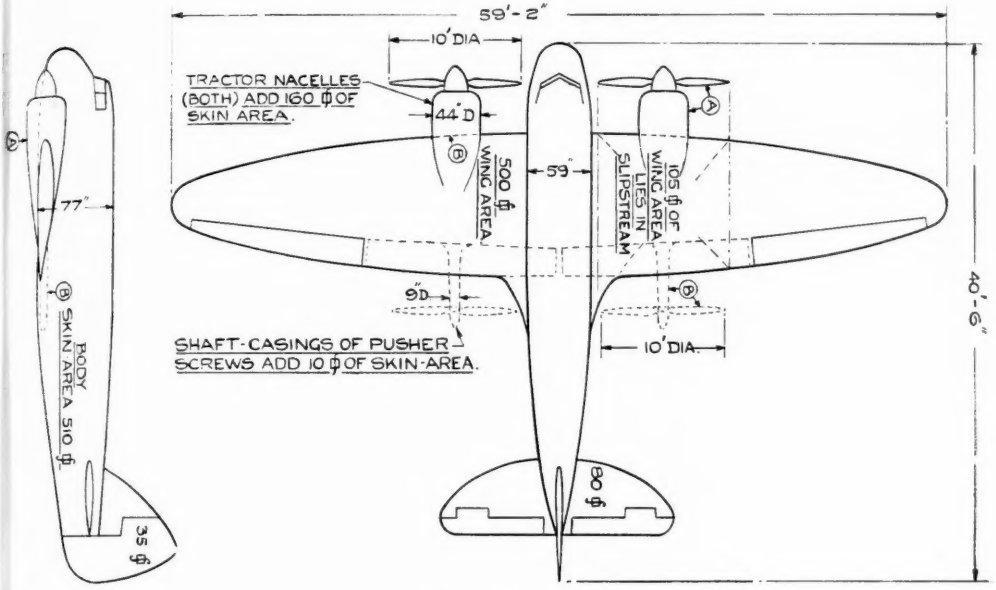


FIG. 9 (*a*) (*b*).

Civil transport.

$W = 15{,}000$lbs. $A = 500$ sq. feet. b.h.p. (total) $= 1{,}250$.
$E = 90$ per cent. (both cases) so $T = 618{,}750/v$ lbs.
$D_1 = 50{,}600/\rho v^2$ lbs. (both cases).

$$D_F = \begin{cases} 3.08\ \rho v^2 \text{ lbs. for tractor, Fig. 9 } (a), = 2.855\ \rho v^2 \text{ lbs. for pusher, Fig. 9 } (b), \\ \quad \text{when } K_F = 0.0015. \\ 4.79\ \rho v^2 \text{ lbs. for tractor, Fig. 9 } (a), \text{ when } K_F = 0.0024. \end{cases}$$

Cooling drag $= 41{,}250/v$ lbs., *i.e.*, is equivalent to 6 per cent. of b.h.p. (both cases).

		Speed M.P.H. G.L.	Speed M.P.H. 10,000ft.
Tractor M/C,	no cooling drag, $d_{ss} = 0.0148\ T$, $K_F = 0.0015$	290	317.9
,,	6 per cent. cooling drag, $d_{ss} = T\ (0.0148 + 526/\rho v^3)$, $K_F = 0.0015$	281.7	308.9
,,	6 per cent. cooling drag, $d_{ss} = T\ (0.0232 + 526/\rho v^3)$, $K_F = 0.0024$	240.7	263.4
Pusher M/C,	no cooling drag, $d_{ss} = 0.00367\ T$, $K_F = 0.0015$	298	327.6
,,	6 per cent. cooling drag, $d_{ss} = 0.00367\ T$, $K_F = 0.0015$	291	319.0

In above:—d_{ss} = increment of drag due to slipstream.
v = speed in feet per sec.

Civil Aeroplane. Twin Tractor Screws (Fig. 9 (a))

Considering first normal present-day practice of twin tractor airscrews with nacelled engines, as depicted in Fig. 9 (*a*).

It is assumed that the induced drag is unaltered, that it is not affected by the presence of the nacelles nor by the slipstream. For this case then we have:—

$D_1 = 50{,}600/\rho v^2$ lbs. (see Appendix No. 7).

The profile drag is now equal to $0.00568\ A\rho v^2$ lbs. (as before, see Appendix No. 6), plus drag due to nacelles, which we shall assume as of optimum frictional drag only. The extra skin surface due to both nacelles being about 160 sq. feet, the extra drag due to them will be therefore $(160 \times 0.0015\ \rho v^2)$ lbs.

Hence, total profile drag for the machine becomes for this case

$$D_p = (2.84\ \rho v^2 + 0.24\ \rho v^2) = 3.08\ \rho v^2 \text{ lbs.}$$

Certain portions of the machine lie in the slipstream from the airscrews. It is assumed that these parts in the slipstream are:—Nacelles, tail plane and elevators and the strips of wing which lie in the rearward projection of the diameters of the airscrews. The drag of these parts is $1.158\ \rho v^2$ lbs. (see Appendix No. 7).

As the slipstream speed, v_s, must be greater than machine's speed, v, the drag of the parts in the slipstream will be increased by an amount:—

$$1.158\ \rho\ (v_s^2 - v^2) \text{ lbs.}$$

This increment of drag due to slipstream, or slipstream increment, is taken then as

$$d_{ss} = 0.0148\ T \text{ lbs.},$$

where T is airscrew thrust in lbs. (see Appendix No. 8).

As it is assumed that airscrew efficiency is 90 per cent., hence that airscrew thrust $T = 495$ b.h.p./v, and as for this case b.h.p. = 1,250, it follows that

$$T = 618{,}750/v \text{ lbs.},$$

whence $d_{ss} = 9{,}160/v$ lbs.

Speed, Tractor Screws, No Cooling Drag

Equation for speed for this case becomes:—

$$50{,}600/\rho v^2 + 3.08\ \rho v^2 + 9{,}160/v = 618{,}750/v.$$

From which is obtained:—

Speed at G.L. = 290 m.p.h.
Speed at 10,000ft. = 318 m.p.h.

Addition of Cooling Drag

For cooling, air must be allowed to enter the nacelle, flow past the engine and then leave the nacelle; and sufficient mass of air must flow past the engine per second to cool it adequately.

As a figure which represents good present-day practice, it is assumed that the drag necessary for cooling, or the cooling drag, is of amount equivalent to 6 per cent. of the b.h.p. (see Appendix No. 9).

For this case b.h.p. is 1,250, hence it follows that 75 b.h.p. will be absorbed in cooling both engines. Hence, cooling drag will be $(75 \times 550)/v$ lbs., or $41{,}250/v$ lbs., at a speed of v feet per second.

Further, for this tractor case, this cooling drag will lie in the slipstream, whence slipstream increment, d_{ss}, becomes for this case equal to

$$T\ (0.0148 + 526/\rho v^3) \text{ (see Appendix No. 10).}$$

Equation for speed has now become

$$50{,}600/\rho v^2 + 3.08\ \rho v^2 + 41{,}250/v = (618{,}750/v)\ [1 - (0.0148 + 526/\rho v^3)].$$

From which is obtained:—

Speed at G.L. ($\rho = 0.00237$) = 282 m.p.h.
Speed at 10,000ft. ($\rho = 0.001756$) = 309 m.p.h.

It will be noticed, therefore, that an addition of cooling drag, equivalent to 6 per cent. of the b.h.p., has caused a loss of speed of about 2.8 per cent. when this cooling drag lies in the slipstream.

Twin Pusher Screws (Fig. 9 (b))

This case represents an ideal, engines being completely enclosed in the wings (or in the body) and causing no alteration of, or addition to, the external shape.

This could be achieved by special flat type engines in the wings with straight shaft drives, or by engines in the body with drives by shafts and bevel gears. Obviously, either type of power plant would be of considerably greater weight than the normal, would occasion considerably greater structural and mechanical difficulties and would decrease accessibility. The comparative values of these disadvantages are not assessed in these notes.

Assuming firstly no cooling drag, the only differences between this machine (Fig. 9 (*b*)) and the stable and controllable aeroplane (of Fig. 8) are:—

(1) Airscrew efficiency is 90 per cent. instead of 100 per cent.
(2) About 10 sq. ft. of skin surface is added by the shaft casings, hubs and tail fairings of the pusher screws.
(3) The tail plane and elevators lie in the slipstream.

For this case then:—

Induced drag, $D_i = 50{,}600/\rho v^2$ lbs. (as before).
Profile drag, $D_p = 2.84\ \rho v^2$ (as before), plus $(10 \times 0.0015)\ \rho v^2$,
or $D_p = 2.855\ \rho v^2$.
Airscrew thrust, $T = 618{,}750/v$ (as before).

Drag of parts in slipstream, meaning tail plane and elevators only, is $(1.2 \times 80 \times 2 \times 0.0015)\ \rho v^2$ or $0.288\ \rho v^2$ for both airscrews.

Hence, slipstream increment

$d_{ss} = 0.00367\ T$ lbs. (see Appendix No. 8)
or $d_{ss} = 2{,}270/v$ lbs.

Twin Pusher No Cooling Drag

Equation for speed for this case becomes:—

$$50{,}600/\rho v^2 + 2.855\ \rho v^2 + 2{,}270/v = 618{,}750/v.$$

From which is obtained:—

Speed at G.L. = 298 m.p.h.
Speed at 10,000ft. = 327.6 m.p.h.

It will be noted that this ideal pusher screw machine (of Fig. 9 (*b*)) is of only about 0.33, lower speed than the practical ideal (of Fig. 8) when the latter is of the same airscrew efficiency (90 per cent.); this is to be expected of course in that the only added drags are 10 sq. ft. of skin surface and slipstream increment over tail.

It will also be noted that with no cooling drag in either case, the normal tractor nacelle machine (of Fig. 9 (*a*)) is of about 2.9 per cent. lower speed than this ideal pusher. But this is mainly due to the different skin surfaces of the two cases, not to airscrew position, as will be seen later.

Twin Pusher with 6% Cooling Drag

If now cooling drag of amount equivalent to 6 per cent. of the b.h.p. be added to this twin pusher aeroplane of Fig. 9 (*b*).

In this case the cooling drag does not lie in the slipstream, so the additional drag will be $41{,}250/v$ lbs. only.

The equation for speed now becomes:—

$$50{,}600/\rho v^2 + 2.855\ \rho v^2 + 43{,}520/v = 618{,}750/v.$$

From which is obtained:—

Speed at G.L. = 291 m.p.h.
Speed at 10,000ft. = 319 m.p.h.

It will be noted that the addition of this cooling drag, of amount equivalent to 6 per cent. of the b.h.p., has resulted in a loss of about 2.5 per cent. of speed, when cooling drag lies outside the slipstream.

It will be noted also that, with cooling drag in both cases, the normal tractor nacelle machine is of about 3.1 per cent. lower speed than this ideal pusher.

This is not an entirely fair comparison, because the same percentage of cooling drag is allowed in both cases and this is assumed as in slipstream for tractor case but as outside slipstream for pusher case. So rather less cooling would be expected in the pusher case, in which the cooling air enters at the machine's speed, than in the tractor case, in which the cooling air enters at the (higher) slipstream speed.

Ideal Tractor Twin Screws

To compare, on an equal footing, the effects of position of airscrews.

Consider that in the ideal pusher aeroplane, of Fig. 9 (*b*), the airscrews (complete with their shaft casings and spinners) are removed from the positions as shown drawn (in dotted lines) and are placed as tractors, *i.e.*, airscrews (altered to tractors, of course) in front of leading edge with their shaft casings projecting from the leading edge.

This arrangement would give an ideal twin tractor comparable fairly with the ideal twin pusher of Fig. 9 (*b*).

With such a lay-out, the equation for speed becomes:—

$$50{,}600/\rho v^2 + 2.855\ \rho v^2 + 7{,}350/v = 618{,}750/v$$

if there be no cooling drag (see Appendix No. 13).

From this is obtained that the speed, at 10,000 feet, would be 326.6 m.p.h.

Hence, on an equal footing the tractor screw machine is only about 0.3 per cent. slower than the pusher, which is to be expected as it has been assumed that the only difference in drag is slipstream increment over the wings and over the shaft casings.

Practical Skin Surfaces

Up to this point it has been considered that all the external skin surface is of optimum frictional drag, *i.e.*, of 0.0015 ρv^2 lbs. per square foot of skin surface (see Appendix No. 1).

In Fig. 10 is given a table of approximate values for skin friction drag coefficient, K_f. Plate glass is the optimum (as at present known), but commercial planished sheet Alclad, at 0.0016, is only about 7 per cent. higher. Fabric and wood, both with the best possible surface finish, are only about 13 per cent. higher.

SKIN FRICTION DRAG COEFFICIENTS K_f.

	K_f
Plate glass	0.0015
Sheet Alclad	0.0016
Linen, doped and varnished	0.0017
Wood, polished and varnished	0.0017
Linen, six coats dope	0.0019
Linen, two coats dope	0.0027

Skin friction drag $D_f = (K_f \times A_s \times \rho v^2)$ lbs.

(N.B.—For wing $A_s \doteq 2A$.)

A_s = skin area in sq. feet.

ρ = air density in mass lbs. per cubic foot.

v = speed in feet per second.

FIG. 10.

Polished sheet metal, or polished wood, or polished fabric, will probably remain as skin substances and it would appear that with any one of these, little appreciable loss should be suffered from lack of finish or roughness of the surface itself.

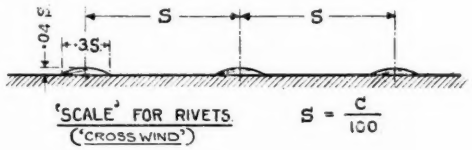
But the skin has got to be fastened on. In the case of wood this is easy to do without impairing the final surface. Fabric must be sewn on by some method or other, and some extra drag is almost certain to be incurred thereby. It is probable that in the near future sheet metal skin may be attached by spot welding, leaving a surface practically unimpaired; but spot welding is not yet satisfactory. Riveting is the only reliable method at present for the attachment of sheet metal skin. Methods for employing the countersunk form of rivet are being developed, but the use of this form necessarily occasions greater manufacturing difficulties and more complicated processes than does the use of a square-shouldered form of rivet.

The mushroom head form of rivet has been used largely up to now, because the riveting process is simple, the finished riveting is reliable and the shape of head looks as if it should add very little drag.

In the sketch at the top of Fig. 11 is given a normal scale for a row of mushroom head rivets lying along the span of a wing, *i.e.*, the row is cross wind. The spacing is assumed as equal to one hundredth of the wing chord, the diameter of the head is 30 per cent. of the spacing, the height of the head 4 per cent. of the spacing.

The curves at the foot of Fig. 11 give the effect on drag of such a row of rivets.

A single row on the top surface alone, adds 0.00042 of K_f value, *i.e.*, adds about 28 per cent. to the optimum frictional drag, when this row is located at about 0.07 of the chord length behind the leading edge. A single row on the bottom surface causes only about 40 per cent. of the additional drag due to a similarly placed row on the top surface.



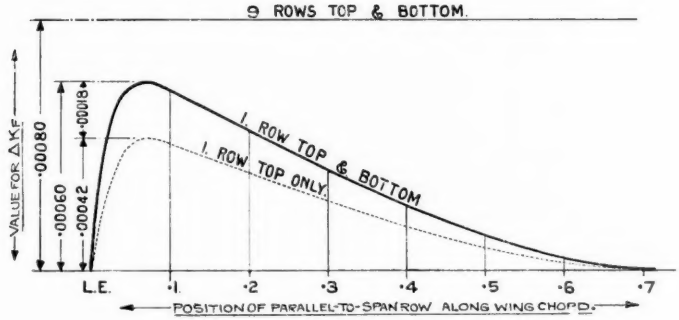


FIG. 11.

Effect of rivet heads on wing surface.
ΔK_F (increment to K_F).
Skin friction drag $= (K_F + \Delta K_F) A_s \rho v^2$ lbs.
A_s = skin area = 2.1 (for wing).

Nine rows of rivets, in both top and bottom surfaces, located at about 0.05, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70 and 0.80 of the chord from the leading edge, cause an addition of about 0.0008 of K_f value, *i.e.*, add about 53 per cent. to the optimum frictional drag.

The foregoing results are based on the results of experiments in the 24ft. tunnel of the N.A.C.A. (see Technical Note No. 461) and of experiments made in the wind tunnel of the Bristol Aeroplane Company. The two sets of experimentally determined figures agreed remarkably well when allowance was made for the different scale of rivets used. The figures given here are more or less a mean of the N.A.C.A. and of the Bristol figures. These figures are not quoted as of proven accuracy, but they probably are of approximate accuracy.

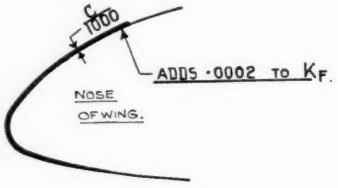


FIG. 12.

Effect of parallel-to-span skin lap.

It is possible again that lap joints may be used in the skin. In Fig. 12 is illustrated a result obtained from experiment in the wind tunnel of the Bristol Aeroplane Company. This indicates that a down wind step, of height equal to about one thousandth of the wing chord, causes an addition of 0.0002 of K_f value, *i.e.*, adds about 13 per cent. to optimum frictional drag. This is the result of an isolated test and is not quoted as data, but merely as an indication that lands of skin-plating parallel to wing span probably cause appreciable increase in drag.

Effect of Increase of Skin Friction Drag Only

If it be assumed that sheet Alclad be used for the skin covering and that this covering be attached by mushroom-headed rivets, it would appear that the skin friction drag might be $(0.0016+0.0008)\ \rho v^2$, or $0.0024\ \rho v^2$, instead of the optimum figure of $0.0015\ \rho v^2$ which has been used so far; and this with what might be considered quite good present-day practice.

Taking this value of 0.0024 then, and considering only the case of

30lbs. per sq. foot wing loading,
12lbs. per sq. foot power loading,
10,000ft. height (when $\rho=0.001756$),

as sufficiently illustrative.

Speeds with K_f Increased from 0.0015 to 0.0024

For flying wing (see Appendix No. 11) equation for speed becomes:—

$$81.82/0.001756\ v+(0.0048\times 0.001756)\ v^3=1,375$$

whence speed = 364 m.p.h. (about 15 per cent. reduction).

For stabilised wing (see Appendix No. 11) equation for speed becomes:—

$$101.2/0.001756\ v+(0.00701\times 0.001756)\ v^3=1,375$$

whence speed = 318 m.p.h. (about 15 per cent. reduction).

For stable and controllable of Fig. 8 (see Appendix No. 11) equation for speed becomes:—

$$101.2/0.001756\ v+(0.00881\times 0.001756)\ v^3=1,375$$

whence speed = 294 m.p.h. (about 14 per cent. reduction).

For the civil transport, with twin tractor nacelles of Fig. 9 (*a*), with cooling drag equivalent to 6 per cent. of the b.h.p., the equation for speed now becomes:—

$$50{,}600/\rho v^2 + 4.79\ \rho v^2 + 41{,}250/v = 618{,}750/v\ [1 - (0.0232 + 526/\rho v^3)]$$

(see Appendix No. 12)

and $\rho = 0.001756$ for 10,000 feet altitude,

whence speed = 263 m.p.h. (about 14.7 per cent. reduction).

It is somewhat startling to see what an enormous alteration of speed can apparently be incurred by a relatively minor alteration of skin surface.

Speed with Reduced Power

Suppose that for the twin tractor nacelled aeroplane, of Fig. 9 (*a*), with 6 per cent. cooling drag, the engines be throttled to 60 per cent. of their full power. The b.h.p. is now 750 instead of 1,250, and there is no other alteration; so it follows that the equation for speed has now become:—

$$50{,}600/\rho v^2 + 3.08\ \rho v^2 + 24{,}750/v = (371{,}250/v)\ [1 - (0.0148 + 315/\rho v^3)].$$

From this is obtained that the speed, at 10,000 feet, is 248 m.p.h.

Comparing this with the same case at full power it appears that a reduction to 60 per cent. of power causes a reduction to (slightly over) 80 per cent. of speed; or 40 per cent. off power means (barely), 20 per cent. off speed.

SUMMARY.—The speeds, at 10,000 feet, and itemised percentage drags for the types of machine that have been considered, are collected in Table No. 1 for purposes of convenient comparison.

Speeds and drags are given in this table to what might be considered a ridiculous degree of arithmetical accuracy in view of the general degree of accuracy of the methods. This is done to give better comparative differences where such differences are small. It is probable that the percentage differences are reasonably accurate although the actual figures may not be so.

Weights

It is necessary to touch upon the question of weights, because weights of air frame structure and of power plant are of primary importance when examining the usefulness of an aeroplane. Obviously, the greater the percentage of the total weight necessary for air frame structure and for power plant, the lower is the percentage of total weight available for load.

Structure Weight

On Table No. 2 are given some equations for air frame structural weights. These have been evolved from such data as one has been able to collect and analyse.

It is advisable to offer some explanation of the first equation; that for weight of wings in lbs. per sq. foot of wing area. This equation is based upon the square-cubed law for similar structures, *i.e.*, structures of different sizes, but geometrically similar throughout and of the same materials, will be subjected to the same unital stresses if they be subjected to the same unital loading.

From this law it follows that if wings of different sizes be made throughout simply by working to different scales from the same drawings, the weight of such wings will vary as the cube of any linear dimension (say the span), but the stress load they are equally competent to bear will vary as the square of the same linear dimension.

This law is qualified because:—

(1) A larger structure can, in practice, be made more refined in detail than can a smaller one.

(2) The individual members of a structure can, in practice, generally be made of more efficient form for a more highly stressed structure than for a less highly stressed structure.
(3) To a certain point, load factors are allowed to be lower for a heavier than for a lighter aeroplane.

The first term in brackets of this equation, $(1 - A/8{,}000)$, is intended to make allowance for detail improvement with increased size of structure; this factor is assumed to reach its limiting value, of 0.75, for a wing area of 2,000 sq. ft. and to remain then constant for larger area.

The second term in brackets, $\{1 - (F\omega - 50)/1{,}000\}$, is intended to make allowance for increased efficiency of detail shapes with increased stress loading; this factor is assumed to reach its limiting value, of 0.75, when $F\omega$ reaches a value of 300 and to remain then constant for higher values of $F\omega$.

The constant, 0.8lbs. per sq. foot, of this equation may logically be defended by the argument that a wing must be of some weight even though it be subjected to no stress load.

In Tables Nos. 3 and 4 are given values for structure weights which have been obtained from the equations of Table No. 2. In both of these tables (Nos. 3 and 4) the weights are expressed as percentages of W the total weight of the aeroplane. F is the load factor, C.P. forward, required for normal category airworthiness.

Table No. 3 shows how for a fixed total weight (6,000lbs. in the particular example) the structure weight decreases as the wing loading is increased, meaning, of course, as the whole air frame is made smaller.

Table No. 4 shows how alteration of size affects structure weight. In this example wing loading is assumed as constant at 30lbs. per sq. foot.

From Table No. 3 it would appear that raising the wing loading from 20lbs. per sq. foot to 40lbs. per sq. foot (or halving the wing area for the same weight of aeroplane) gives a decrease of structure weight of about 8.3 per cent. of total weight; or decreases the structure weight itself by nearly 30 per cent.

Table No. 4 shows how the structure weight rises from less than 23 per cent. of the total weight, when this is 6,000lbs., to slightly over 49 per cent. of the total weight, when this is 210,000lbs. (93.75 tons).

Power Plant Weights

In Table No. 5 are given weights for power plant, in lbs. per b.h.p. (normal maximum). The figures quoted in this table are intended to represent about the best present-day practice.

Total weight of dry power plant is 1.99lbs. per b.h.p. (maximum normal).

In this Table No. 5 are given also weights for fuel, oil and tanks, expressed in lbs. per b.h.p. per hour.

Weight of fuel and oil, with tankage for both included, is given here as 0.578lbs. per b.h.p. per hour, plus 22lbs. (per engine) for reserve oil with the extra oil tankage capacity thereby necessitated.

These power plant weights are assumed in order that questions of load may be looked into. They are considered reasonable, but it is neither intended nor suggested that they are accurate data.

Weights and Performance of Aeroplane

In Table No. 6 are given the weights and thence the possible loads, for a hypothetical aeroplane. The type chosen is that drawn in Fig. 9 (*a*), see also Type E of Table No. 1; a twin-engined tractor-screws, low wing monoplane of 500 sq. ft. wing area, of 15,000lbs. total weight and of 1,250 normal maximum b.h.p. (for both engines). The level speed, at 10,000ft., altitude, for this machine

is 308.9 m.p.h. at full power, 1,250 b.h.p., or 248.1 m.p.h. with engines throttled to 60 per cent. of full power, 750 b.h.p.

This type is selected from amongst those which have been considered in these notes, as representing probably the safest compromise at the present stage of development.

Two examples of equipment for this aeroplane are considered:—

(1) As a pure duration machine, carrying only pilot, flying instruments and electrical equipment; all the rest of the load (8,150lbs.) being devoted to fuel (964 galls.), and oil (36 galls.) with tankage (520lbs.).

At full speed (308.9 m.p.h.) and full power (1,250 b.h.p.) at 10,000 feet, the duration would be 11.22 hours, or 3,470 air miles.

Throttled to 60 per cent. full power (750 b.h.p.) at 10,000 feet, and assuming the same consumption per b.h.p. hour, the duration would be, of course (11.22 ÷ 0.60), *i.e.*, 18.7 hours, therefore 4,640 air miles as the speed would be then 248.1 m.p.h.

(2) As a passenger transport with a crew of two, all flying and navigating instruments, electrical and W./T. equipments, all equipment and furnishings for passenger accommodation and 14 passengers with baggage, 462 gallons of fuel and 19 gallons of oil, with tankage, can be carried.

At full speed and power (as before), at 10,000ft., the duration would be then 5.38 hours, whence 1,660 air miles (at 308.9 m.p.h.). Throttled to 750 b.h.p. (as before), at 10,000ft., the duration would become 8.97 hours, whence 2,220 air miles (at 248.1 m.p.h.).

Probably these durations are unnecessarily high and a better paying proposition would be achieved by carrying more passengers and less fuel and oil. Obviously, any particular allocation of the 8,150lbs. left for load (see Table No. 6) would be made to suit any particular operational requirements.

That finishes these notes as regards the presentation of data, of methods of calculation and of examples.

It is dangerous to be inaccurate in technical notes, it is criminal to be misleading, so it is hoped that the presentation has been sufficiently detailed and explicit to ensure at least against their being misleading.

Conclusions

Taking the findings for what they are worth as they stand, certain points show up in rather significant manner, so perhaps it is justifiable to assess the relative merit of different lines along which improvement might be effected.

Turbulence and Interference

It has been assumed throughout these notes *that turbulence drag and interference drag are entirely avoided* (except for eyebrow of body and breaks due to control surfaces). If this were so nothing further could be achieved here. But it must be noted that operational requirements generally necessitate *a considerable measure of both turbulence and interference*. All that can be done then is to effect the best compromise between operational efficiency and drag. Machine type E2 of Table No. 1, with riveted skin, is considerably faster than nearly all existing machines at the same height, wing loading and power loading; this loss must be debited to turbulence and interference on existing machines. Perhaps it might be stated that turbulence and interference should be largely avoidable by the aeroplane designer except in so far as they are forced on him by operational requirements. Their potency cannot therefore be assessed generally, it is decided largely by the specification for any particular type.

Skin Friction

If turbulence and interference be avoided, by far the largest item of drag is skin friction, hence every effort must be directed towards attaining a " suant " and polished surface to the whole of the external skin, and to reducing the parasite skin area.

Cooling Drag

Cooling drag is not necessarily an item of great importance. Type E2 of Table No. 1 is 14.7 per cent. slower that type E1, but type E1 is only 2.8 per cent. slower than type E. So the 6 per cent. cooling drag only causes about one-fifth of the damage occasioned by rivet heads on the skin.

It should be noted that cooling drag as low as that equivalent to 6 per cent. of the b.h.p., is not achieved at present on fast machines at top speed; 12 per cent. is a more normal figure. But 6 per cent. can be achieved at lower speeds, so there seems no basic reason against its being achieved at any speed; this because a constant mass flow of air per unit time per b.h.p. is required for cooling, and this means constant cooling drag per b.h.p.; if turbulence losses can be avoided in leading the air into and out of the cowling. Controllable cowling and considerable development work on entry and on exit are called for; but this matter does not appear so important as smoothness of skin surface, nor to present such difficult problems in actual practice.

Weight

Any weight saving in air frame structure and power plant is of value, in that this saving may be added directly to load. This matter is mainly a question of developments in detail design and in metallurgy. It does not appear likely that any great gains can be achieved.

Thermal Efficiency

The greatest obvious gain from power plant would be increase of thermal efficiency. The quoted figure of 0.55 pint (or 0.52lb.) of fuel per b.h.p. per hour means a thermal efficiency of about 27 per cent. Any improvement on this would mean a direct saving in weight (and bulk) of fuel, and a decrease in the drag and weight incurred in providing cooling; the former gain would be much greater than the latter.

A more concentrated fuel, one providing more heat units per lb. and/or per gallon, would be of great advantage.

The foregoing statements are so obvious that one feels apologetic about making them, for they must be fully recognised by the people on the job.

Airscrew

For flight conditions, little gain in airscrew efficiency can be expected and it seems unlikely that any other form of thrust producer more efficient than the airscrew will be evolved. For very high speed machines with their necessarily high speeds for take-off, the problem of take-off becomes a very serious one. Airscrews of infinitely variable pitch become a necessity, likewise the ability to run the engines at specially high power and r.p.m. for the take-off.

The outstanding development required for the infinitely V.P. airscrew is that to afford decrease of weight whilst retaining blades of the best aerodynamic form.

General Layout

Obviously, the more an aeroplane approaches a flying wing the better for performance. In this respect the large machine has advantages over the small, because the cross-sectional dimensions of its body may probably be made smaller relative to its wing size.

Whether the top of the body should be flush with the top of the wing surface (high wing), whether the wing should pass through the centre of the body (mid-wing), or whether the bottom of the body should be flush with the bottom of the wing (low wing), is a debatable subject.

The mid-wing occasions the least fear of interference drag, the low wing occasions the greatest. But by suitably filleting junction of wing and body, very little interference drag should be present with the low wing; the added skin surface of the filleting means, however, extra skin friction drag. Actually, whether high, mid or low wing is determined more by operational requirements than by aerodynamic considerations.

Pusher screws offer slight advantages, but for fair comparison this advantage lies only in reduction of slipstream increment. Tractor type E (of Table No. 1) is nearly 3 per cent. slower than pusher type D, but this is mainly because of the added skin area of the nacelles of type E. Buried engines can equally well drive pusher or tractor airscrews, and with buried engines in both cases (instead of only for the pusher case, type D) tractor type DT is only about 0.3 per cent. slower than pusher type D.

In weighing the relative merits of tractor and pusher screws, the probable superiority of tractor screws for take-off should be carefully assessed, particularly as take-off appears likely to become the most difficult problem in the design of high-speed aeroplanes.

Buried engine is necessarily a highly controversial subject. Superficially, the reduction of skin area, of blind spots in field of vision and of possible sources of interference, afford very strong arguments for buried engines. But the counter arguments are strong also, particularly when it comes to the practical questions of construction and of operation. Weight of dry power plant would be higher per b.h.p.; structural problems would be more difficult and structure weight probably increased; accessibility might present some very sticky problems; difficulty might be encountered in getting the C.G. of the whole aeroplane correctly located without resource to a very long nose to the body or/and a sweep-back of the wings, either procedure being of aerodynamic disadvantage. More data and research are necessary before the merits and demerits of buried engines can be reasonably assessed.

Finally one enters a plea for opposite-turning airscrews.

By opposite-turning airscrews is meant:—

(1) An equal number of airscrews, paired on either side of the vertical central plane of symmetry of the aeroplane, each such pair then turning in opposite directions.

(2) Co-axial airscrews, one immediately behind the other (say on a single central engine), turning in opposite directions.

The only objection to (1) is the question of spares and stores; (2) has great attraction for single-engine aircraft of very high power to span ratio, but it presents one serious difficulty; it would appear almost impossible to design co-axial airscrews with variable pitch mechanism, and if this system cannot be produced with variable pitch it would appear hardly worth producing at all for future requirements.

It is true that the difference in performance, due solely to opposite-turning as against all airscrews (of a multi-screw machine, of course) turning in the same direction, may be of very small amount. But an aeroplane with a symmetrical disposition of airscrews should have definite advantages for manœuvring and for navigating, and such advantages would be more marked the higher the power per weight, or, perhaps more correctly the higher the ratio of power to wing span. It seems probable also that symmetrical airscrew arrangements might reduce the risk of vibrations, particularly of the tail surfaces.

Appendix No. 1

Skin Friction Drag.

Skin friction drag represents the result of complicated rather than of simple physical processes and is extremely difficult to measure accurately; so it is dangerous to give a measure of it in a simple engineering form, as has been done in these notes.

Pure skin friction drag should represent only the momentum (or the alteration in momentum) given to the air per unit time when and because it is (relatively) flowing over a smooth surface of a body; but it would appear almost certain that some degree of turbulence is set up in the boundary layer as well.

By the boundary layer is meant that hypothetical layer inside which the air (due to skin friction) is more or less stationary with respect to the surface, outside which the air is stationary with respect to itself.

Hence, given pure skin friction, one would expect the surface of the boundary layer to touch the surface of the body at its leading edge and to lie uniformly farther and farther away from the surface of the body to a maximum at the trailing edge.

Because of the (relative) speed of the air over the surface of the body there must be alterations in the static pressure of the air upon the surface of the body. As the air inside the boundary layer is more or less stationary with respect to the body, it might be considered as forming part of, or an accretion upon the surface of the body.

Hence, there must be alterations of pressure across the boundary layer.

Should this alteration of pressure become too great (as might be caused by excessive curvature of the surface of the body) or should the boundary layer thicken too rapidly (as might be caused by a surface not sufficiently smooth) the boundary layer will break down and become turbulent, with resultant increase of drag.

Probably all measurements of skin friction drag include a certain amount of drag due to turbulence of the boundary layer.

It is assumed in these notes that $0.0015\ \rho v^2$ lbs. per square foot of surface area represents pure skin friction drag and is constant over the whole surface area irrespective of shape, size or speed; this assumption is more or less inaccurate, probably dangerous.

This Appendix is submitted in the hope that it may be approved, or corrected, or contradicted, in whole or in part by others more competent than myself to deal with the subject.

Skin friction drag should be the biggest factor (and much the biggest) affecting the speed of a fast aeroplane; so, in addition to being a subject of great interest, it would appear to be one of vital importance.

Appendix No. 2

Flying Wing (see Fig. 2).

General equation for speed (see Figs. 1 and 2) is:—

$$(1/11)\ (W^2/A)\ (1/\rho v^2) + 0.003\ A\rho v^2 = 550\ \text{b.h.p.}/v \quad . \quad . \quad (1)$$

$W/\text{b.h.p.} = 12$ and $\rho = 0.00237$ (ground level).

Hence, taking A as unity equation becomes:—

$$(1/11)\ (W^2)\ (1/0.00237\ v^2) + (0.003 \times 0.00237\ v^2) = 550\ W/12\ v$$

$$\text{or}\quad W^2/0.0021725\ v + 0.00008532\ v^3 = 550\ W \quad . \quad . \quad . \quad (2)$$

STABILISED WING (SEE FIG. 6).

D_i being 1.237 times that for flying wing,
Skin area being 1.46 times that for flying wing, } see Fig. 5.

Equation for speed becomes:—

$$1.237\ W^2/0.0021725\ v + 1.46\ (0.00008532\ v^3) = 550\ W \text{ from (2)}$$
$$\text{or } W^2/0.001756\ v + 0.0001246\ v^3 = 550\ W \quad . \quad . \quad . \quad (3)$$

It should be noted that in above equations, (2) and (3), $W = W/A$, as A has been taken as unity, hence

W = wing loading in these equations in lbs. per sq. foot.
v = speed, feet per second.

APPENDIX No. 3

FLYING WING (SEE FIG. 3).

Using equation for speed (1) of Appendix No. 2 with
$W/A = 30$ and $\rho = 0.00237$ (ground level)
power loading W/b.h.p. = 30 A/b.h.p.
or b.h.p. = 30 A/power loading.

Hence, equation for speed becomes:—

$$(900\ A^2/11\ A)\ (1/0.00237\ v^2) + (0.003 \times 0.00237\ Av^2) = 16{,}500\ A/v \text{ (power loading)}$$
$$\text{or } 34{,}500/v + (0.0711/10^4)\ v^3 = 16{,}500/\text{power loading} \quad . \quad . \quad (4)$$

v = speed, feet per second. Power loading in lbs. per b.h.p.

APPENDIX No. 4

FLYING WING (SEE FIG. 4).

Using equation for speed (1) of Appendix No. 2 with:—
$W/A = 30$ or $W = 30\ A$
and W/b.h.p. = 12 whence b.h.p. = 2.5 A.

Hence, equation for speed becomes:—

$$900\ A^2/11\ A\rho v^2 + 0.003\ A\rho v^2 = 1{,}375\ A/v$$
$$\text{or } 81.82/\rho v + 0.003\ \rho v^3 = 1{,}375 \quad . \quad . \quad . \quad . \quad (5)$$

STABILISED WING (SEE FIG. 7).

D_i being 1.237 times that for flying wing,
Skin area being 1.46 times that for flying wing, } see Fig. 5.

Equation for speed becomes:—

$$1.237\ (81.82/\rho v) + 1.46\ (0.003\ \rho v^3) = 1{,}375 \text{ from (2)}$$
$$\text{or } 101.2/\rho v + 0.00438\ \rho v^3 = 1{,}375 \quad . \quad . \quad . \quad . \quad (6)$$

In above equation, (5) and (6),

ρ = air density in mass lbs. per cubic foot.
v = speed, feet per second.

Appendix No. 5

Flying Wing.

Taking $W/A = 100$ or $W = 100\,A$

$W/\text{b.h.p.} = 5$ or $\text{b.h.p.} = W/5 = 20\,A$

$\rho = 0.000361$ (height being 50,000 feet).

Equation for speed (1) of Appendix No. 2 becomes:—

$$(10{,}000/11\,A)\,(A^2/0.000361\,v^2) + (0.003 \times 0.000361)\,Av^2 = 11{,}000\,A/v$$

$$\text{or } 10^6/0.3961\,v + (1.083/10^6)\,v^3 = 11{,}000 \quad . \quad . \quad . \quad (7)$$

whence $v = 2{,}083$ ft./sec. or $V = 1{,}420$ m.p.h.

If $S = 20$ feet:—

From Fig. 1 $A = 400/7$ sq. ft. (as $A = S^2/7$)

whence $W = 40{,}000/7$ lbs. (as $W = 100\,A$ in lbs.)

whence $\text{b.h.p.} = 40{,}000/35 = 1{,}143$ (as $\text{b.h.p.} = W/5$)

Maximum chord (from Fig. 1) $= 0.182\,S = 43.7$in.

Maximum thickness $= 15$ per cent. maximum chord $= 6.55$in.

Appendix No. 6

Stable and Controllable with Practical Body (see Fig. 8).

$$D_i = (1.237/11)\,(W^2/A)\,(1/\rho v^2) \text{ lbs.}$$

$$D_p = (0.00315 + 0.00170 + 0.00083)\,A\rho v^2 \text{ lbs.} = 0.00568\,\rho v^2 \text{ lbs.}$$

$$T = 550 \text{ b.h.p.}/v \text{ lbs.}$$

with $W/A = 30$ or $W = 30\,A$ and $W/\text{b.h.p.} = 12$ or $\text{b.h.p.} = 2.5\,A$.

Hence, equation for speed becomes:—

$$(1.237 \times 900\,A^2)/11\,A\rho v^2 + 0.00568\,A\rho v^2 = 1{,}375\,A/v$$

$$\text{or } 101.2/\rho v + 0.00568\,\rho v^3 = 1{,}375 \quad . \quad . \quad . \quad (8)$$

If propulsive efficiency be only 90 per cent.

$$T = 495 \text{ b.h.p.}/v \text{ lbs.}$$

and equation for speed becomes:—

$$101.2/\rho v + 0.00568\,\rho v^3 = 1{,}237.5 \quad . \quad . \quad . \quad . \quad (9)$$

Appendix No. 7

Civil Transport (see Fig. 9 (*a*)).

$D_i = (1.237/11)\,(W^2/A)\,(1/\rho v^2)$ lbs. (as for stabilised wing).

But for this case:—

$W = 15{,}000$ lbs. and $A = 500$ sq. ft.

so $D_i = 50{,}600/\rho v^2$ lbs.

$$D_p = [0.00568\,A\rho v^2 + (160 \times 0.0015\,\rho v^2)] \text{ lbs.,}$$

whence, as $A = 500$ sq. ft., $D_p = 3.08\,\rho v^2$ lbs.

$T = (0.9 \times 550 \text{ b.h.p.})/v$ and b.h.p. $= 1{,}250$ (both engines)

whence $T = 618{,}750/v$ lbs.

Drag of parts in slipstream:—

Nacelles $(160 \times 0.0015)\,\rho v^2 = 0.240\,\rho v^2$ lbs.

Tail plane and elevators $(1.2 \times 80 \times 2 \times 0.0015)\,\rho v^2 = 0.288\,\rho v^2$ lbs.

Wing strips $(2 \times 105 \times 2 \times 0.0015)\,\rho v^2 = 0.630\,\rho v^2$ lbs.

Total $= 1.158\,\rho v^2$ lbs.

or $0.579\,\rho v^2$ lbs. per airscrew.

Appendix No. 8

Slipstream Increment, d_{ss}.

If $K_D \rho v^2$ lbs. be drag of parts in slipstream, then slipstream increment

$$d_{ss} = K_D \rho (v_s^2 - v^2) \text{ lbs.} \quad . \quad . \quad . \quad . \quad (1)$$

where ρ = air density, mass lbs. per cubic foot.
v_s = slipstream speed, in feet per sec.
v = aeroplane's speed, in feet per sec.

Airscrew thrust $T = \frac{1}{2} \rho A_s (v_s^2 - v^2)$ lbs. . . . . (2)

where A_s = cross-sectional area of slipstream in sq. feet.

Hence, from (1) and (2):—

$$d_{ss} = (2K_D / A_s) T \text{ lbs.} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Assuming that $A_s = \pi D^2/4$ sq. feet, where D is airscrew diameter in feet, is obtained:—

$$d_{ss} = (8/\pi) (K_D / D^2) T \text{ lbs.} \quad . \quad . \quad . \quad . \quad (4)$$

For case of Fig. 9 (*a*), where $K_D = 0.579$ per airscrew and $D = 10$ ft.:—

$$d_{ss} = (8/\pi) (0.579/100) (T/2) \text{ lbs. per airscrew}$$
$$\text{or } d_{ss} = 0.0148\ T \text{ lbs. total,}$$

i.e., for both airscrews, where T is total thrust in lbs.

For case of Fig. 9 (*b*), where $K_D = 0.144$ per airscrew and D is again 10ft.:—

$$d_{ss} = (8/\pi) (0.144/100) (T/2) \text{ lbs. per airscrew}$$
$$\text{or } d_{ss} = 0.00367\ T \text{ lbs. total.}$$

Appendix No. 9

Cooling Drag.

Cooling drag is a subject upon which misunderstanding may arise unless what is meant by the term be defined quite clearly. Cooling drag is intended here to mean, and to mean only, the added drag occasioned by letting, to and from the engine, sufficient air to cool the engine adequately. Hence, thus defined, cooling drag means the difference in drag between:—

(*a*) The drag of the aeroplane in the condition requisite for cooling; and
(*b*) The drag of the aeroplane with the inlets and outlets (for the passage of the cooling air) sealed and faired up.

Hence, for a tractor screw single-engined aeroplane with engine mounted in nose of body, there need be no extra drag due to the engine other than cooling drag, if the engine be of such shape and size that it will fit into a low drag form of nose.

For a single-engined, or multi-engined, aeroplane with the engines buried in the body or in the wings, but with the airscrews mounted on the wings, there need be no extra drag due to engines other than cooling drag, save a very small added profile drag due to shaft casings.

But for a tractor nacelle aeroplane, as depicted in Fig. 9 (*a*), in addition to cooling drag there should be debited as due to engines the drag due to the addition of the nacelles when these nacelles are sealed and faired up; but this increment of drag due to sealed up and faired up nacelles is not cooling drag as here defined.

It is obvious that a controllable form of cowling is necessitated when cooling drag is assumed as being equivalent to a fixed percentage of the b.h.p. of the engine. For if cooling drag be equivalent to some fixed percentage, say n per cent., of the b.h.p., it follows that

$$\text{Cooling drag} = (n \times 550 \text{ b.h.p.})/100\ v \text{ lbs.}$$

when v is the air speed of the aeroplane in feet per second; hence, the higher the speed of the aeroplane the lower must be the cooling drag in lbs. per b.h.p.

Were the cowling of a fixed form the cooling drag would then increase as the square of the speed.

The cooling drag of any particular installation is usually determined by wind tunnel tests and, from the results of such tests, is labelled as being so many pounds at a wind speed of 100 feet per second at standard ground level air density, *i.e.*, at a value for ρv^2 of 23.7.

So if aeroplane X be twice as fast (with the same b.h.p. and at the same altitude) as aeroplane Y, then must the cooling drag of X (at its higher speed) be only one half of that of Y (at its lower speed) if the cooling drag for both aeroplanes is to be equivalent to the same percentage of the b.h.p. Hence, at the same speed and air density (as when $\rho v^2 = 23.7$) the cooling drag for X must be only $(\frac{1}{2}) \times (\frac{1}{2}^2)$ or one-eighth of that of aeroplane Y.

Appendix No. 10

Slipstream Increment when Cooling Drag Lies in Slipstream.

From Appendix No. 8, slipstream increment

$$d_{ss} = (8/\pi)\ (K_D/100)\ (T/2) \text{ lbs. per airscrew,}$$

for aeroplane of Fig. 9 (*a*), where $K_D \rho v^2$ lbs. is drag of all parts in slipstream of one airscrew and T is thrust of both airscrews.

Cooling drag $= (\frac{1}{2})\ (6/100)\ (1{,}250)\ (550/v)$ lbs. $= 20{,}625/v$ lbs. per airscrew.

Drag of all other parts in each slipstream is

$$0.579\ \rho v^2 \text{ (from Appendix No. 7).}$$

Hence, for drag of all parts in each slipstream

$$K_D = [0.579 + 20{,}625/\rho v^3].$$

Hence, for both airscrews, slipstream increment

$$d_{ss} = (8/\pi)\ (T/100)\ [0.579 + 20{,}625/\rho v^3] \text{ lbs.,}$$

i.e., total slipstream increment

$$d_{ss} = T\ (0.0148 + 526/\rho v^3) \text{ lbs.}$$

It follows from this that nett thrust, T_N, is given by:—

$$T_N = T\ [1 - (0.0148 + 526/\rho v^3)] \text{ lbs.}$$

In all above:—

T = thrust (total) in lbs.
v = air speed of aeroplane in feet per sec.
ρ = air density in mass lbs. per cubic foot.

Appendix No. 11

K_f for total skin surface increased from 0.0015 to 0.0024, *i.e.*, increased by 0.0009 induced drag, D_i, unaltered.

$$W/A = 30, \quad W/\text{b.h.p.} = 12.$$

Equations for speed are then:—

For flying wing of Fig. 1

$$81.82/\rho v + [0.003 + (2 \times 0.0009)]\ \rho v^3 = 1{,}375$$

(from Appendix No. 4 (5))

$$\text{or } 81.82/\rho v + 0.0048\ \rho v^3 = 1{,}375.$$

For stabilised wing of Fig. 5

$$101.2/\rho v + [0.00438 + (2.92 \times 0.0009)]\ \rho v^3 = 1{,}375$$

(from Appendix No. 4 (6))

$$\text{or } 101.2/\rho v + 0.00701\ \rho v^3 = 1{,}375.$$

For ideal practical of Fig. 8

$$101.2/\rho v + [0.00568 + (3.48 \times 0.0009)]\ \rho v^3 = 1{,}375$$

(from Appendix No. 6 (8))

$$\text{or } 101.2/\rho v + 0.00881\ \rho v^3 = 1{,}375.$$

Appendix No. 12

Twin tractor nacelled civil transport, of Fig. 9 (*a*), with skin drag increased by 0.0009 ρv^2 lbs. per sq. foot of skin area.

$D_i = 50{,}600/\rho v^2$ lbs. (as before, see Appendix No. 7).

$D_p = [3.08 + (1{,}900 \times 0.0009)]\ \rho v^2$ lbs. $= 4.79\ \rho v^2$ lbs.

(see Appendix No. 7 and Fig. 9 (*a*) for skin areas).

Total drag of parts in slipstream, less cooling drag, is now:—

$[1.158 + (740 \times 0.0009)]\ \rho v^2$ lbs. $= 1.824\ \rho v^2$ lbs.

(see Appendix No. 7 and Fig. 9 (*a*) for skin areas).

Cooling drag $= 20{,}625/v$ lbs. per engine, as before

(see Appendix No. 10).

Hence, drag of all parts, including cooling drag, in slipstream of each airscrew is of amount

$$(0.912 + 20{,}625/\rho v^3)\ \rho v^2 \text{ lbs.}$$

and from this, total increment of drag due to slipstream,

$$d_{ss} = (8/\pi)\ (T/100)\ [0.912 + 20{,}625/\rho v^3]$$

(see Appendix No. 10)

$$\text{or } d_{ss} = T\ (0.0232 + 526/\rho v^3) \text{ lbs.}$$

Or total nett thrust

$$T_N = T\ [1 - (0.0232 + 526/\rho v^3)] \text{ lbs.}$$

In all above:—

T = total thrust (both airscrews) in lbs.
v = air speed of aeroplane in feet per sec.
ρ = air density in mass lbs. per cubic foot.

Appendix No. 13

Case of aeroplane exactly as ideal twin pusher, of Fig. 9 (*b*), except that the airscrews, with their shaft casings and spinners, are removed from trailing edge of wing and mounted upon the leading edge of the wing, thus transforming the machine into an ideal tractor aeroplane.

$W = 15{,}000$ lbs., $A = 500$ sq. feet, and b.h.p. $= 1{,}250$, as before.
$H = 10{,}000$ feet, so $\rho = 0.001756$ mass lbs./cubic foot.

Induced drag $D_i = 50{,}600/\rho v^2$ lbs., as before. } Same as for machine of
Profile drag $D_p = 2.855\ \rho v^2$ lbs., as before. } Fig. 9 (*b*).

Drag of all parts in slipstream becomes now:—

$0.288\ \rho v^2$ lbs. for tail plane and elevators.
$0.630\ \rho v^2$ lbs. for wing strips.
$0.015\ \rho v^2$ lbs. for shaft casings.

$0.933\ \rho v^2$ lbs. total for both airscrews.

Hence, for both airscrews, slipstream increment

$$d_{ss} = (8/\pi)\ (0.933/2)\ (T/100) \text{ lbs.} = 0.01188\ T \text{ lbs.}$$

(from Appendix No. 8),

but $T = 618{,}750/v$ lbs. (as before) therefore

$$d_{ss} = 7{,}350/v \text{ lbs.}$$

Equation for speed now becomes:—

$$50{,}600/\rho v^2 + 2.855\ \rho v^2 + 7{,}350/v = 618{,}750/v.$$

Whence, at 10,000 feet ($\rho = 0.001756$):—

$v = 479$ feet per sec. or $V = 326.6$ m.p.h.

TABLE No. 1.

SPEEDS AND ITEMISED DRAGS FOR VARIOUS TYPES.

Drags are all expressed as percentages of 550 b.h.p./v, *i.e.*, of drag equivalent to the b.h.p.

Type.		A	B	C	C_1	D	D_1	D_T	E	E_1	E_2	E_1*
Wing loading		←				30lbs. per sq. foot						→
Power loading, lbs. per b.h.p.		←				12.0						→ 20
Speed, m.p.h.		427.8	374.1	342.1	328.7	327.6	319.0	326.6	317.9	308.9	263.4	248.1
Drags	Induced drag	5.40	7.64	8.35	8.70	8.74	8.96	8.75	9.00	9.25	10.86	19.2
	Profile drag	94.60	92.36	91.65	81.30	80.93	74.71	80.18	79.67	73.13	70.58	63.13
	Cooling drag	0	0	0	0	0	6.0	0	0	6.0	6.0	6.0
	Slipstream increment ...	0	0	0	0	0.33	0.33	1.07	1.33	1.62	2.56	1.67
	Total drag	100	100	100	90	90	90	90	90	90	90	90
Thrust		100	100	100	90	90	90	90	90	90	90	90
550 b.h.p./v		100	100	100	100	100	100	100	100	100	100	100

Height is 10,000 feet in all cases, *i.e.*, $\rho = 0.001756$.

In above table:—

Type A is the flying wing (see Fig. 1 and Fig. 4).
Type B is the stabilised wing (see Fig. 5 and Fig. 7).
Type C is the practical aeroplane with ideal power plant (see Fig. 8).
Type C_1 is as C except that propulsive efficiency is 90 per cent.
Type D is the pusher aeroplane of Fig. 9 (*b*), with no cooling drag.
Type D_1 is as D, but with the addition of 6 per cent. cooling drag.
Type D_T is as D, except that airscrews with shafts and casing are mounted from L.E. of wing, thus altering machine from an ideal pusher to an ideal tractor.
Type E is the tractor aeroplane of Fig. 9 (*a*), with no cooling drag.
Type E_1 is as E, but with the addition of 6 per cent. cooling drag.
Type E_2 is as E_1, except that skin friction drag coefficient is taken as 0.0024, instead of 0.0015 (as in all other types).
Type E_1* is type E_1, but with engines throttled to 60 per cent. of full power, thereby increasing the power loading from 12lbs. per b.h.p. to 20lbs. per b.h.p.

TABLE No. 2.

EQUATIONS FOR STRUCTURAL WEIGHTS.

STRESSED SKIN MONOPLANE.

Wing weight (complete with ailerons) $= (wA)$ lbs.

$$w = (A)^{\frac{1}{2}} (F\omega/970) (1 - A/8{,}000) \{ 1 - (F\omega - 50)/1{,}000 \} + 0.8,$$

where w = weight in lbs. per square foot of wing area.

A = wing area in square feet.

F = load factor, C.P. forward.

ω = stress loading $= (W/A - w)$ lbs. per sq. foot.

W = weight (of fully loaded aeroplane) in lbs.

N.B.—Mass balancing adds 1.5 per cent. of wing weight; flaps, with operating gear, add 6 per cent. of wing weight.

Tail unit (*i.e.*, tail plane, elevators, fin and rudder):—

Weight = 12 per cent. of that of wing weight, *i.e.*, $= 0.12\ wA$.

Body of normal size:—

$[L = 0.62\ (\pm 0.03)\ S.\quad D = 0.10\ (\pm 0.008)\ S.\quad B = 0.08\ (\pm 0.005) S]$.

Weight $= \frac{1}{2}$ that of wings, *i.e.*, $= wA/2$.

L = body length. D = body depth (max.). B = body breadth (max.).

S = wing span.

Undercarriage (retractile):—

Weight $= 0.05\ W$, $W = 30{,}000$lbs. or over.

Weight $= 0.06\ W$, $W = 2{,}000$lbs. or under.

Weight $= [0.05\ W + 0.01\ W \{ (30{,}000 - W)/28{,}000 \}]$ for W.

Between 2,000 and 30,000lbs.

Weight of all flying controls:—

$$= [0.004\ W + 0.5^{*} \sqrt{W}].$$

* This term does not become greater than 100lbs.

TABLE No. 3.

STRUCTURE WEIGHTS.

Alteration of loading, $W = 6{,}000$lbs., $F = 6.14$.

A	W/A	1*	2*	3	4	Total.
300	20	13.00	8.06	5.86	1.05	27.97
250	24	11.47	7.12	,,	,,	25.50
200	30	9.82	6.08	,,	,,	22.81
150	40	7.87	4.88	,,	,,	19.66

TABLE No. 4.

STRUCTURE WEIGHTS.

Alteration of size, $W/A = 30$lbs. per sq. foot.

W	A	1*	2*	3	4	Total	F
6,000	200	9.82	6.08	5.86	1.05	22.81	6.14
9,000	300	10.49	6.51	5.75	0.93	23.68	5.46
12,000	400	10.90	6.76	5.64	0.86	24.16	5
15,000	500	11.70	7.25	5.54	0.81	25.30	,,
21,000	700	12.99	8.06	5.32	0.75	27.12	,,
27,000	900	13.96	8.65	5.11	0.70	28.42	,,
33,000	1,100	14.78	9.16	5.00	0.68	29.62	,,
45,000	1,500	15.85	9.83	,,	0.62	31.30	,,
60,000	2,000	16.64	10.32	,,	0.57	32.53	,,
90,000	3,000	19.45	12.07	,,	0.51	37.03	,,
150,000	5,000	23.67	14.69	,,	0.47	43.83	,,
210,000	7,000	26.93	16.70	,,	0.45	49.08	,,

In above tables (Nos. 3 and 4):—

1 = weight of wings.*
2 = ,, body plus tail unit.*
3 = ,, undercarriage.
4 = ,, aircraft controls.
Total = [1 + 2 + 3 + 4].

} All as percentages of total weight W.

* Neither mass balance nor flaps are here included.

TABLE No. 5.

POWER PLANT WEIGHTS, LBS. PER B.H.P.

	lbs.
Engine, dry, with intakes, heater pipes, mounting units, fuel pumps	1.25
Exhaust system complete	0.09
Cowling complete (controllable)	0.10
Airscrew (three-bladed metal, controllable pitch)	0.34
Engine mounting* (0.063), engine starting (0.050), engine controls (0.013), fuel system (0.013), oil system (0.013), oil coolers (0.025), fireproof bhd. (0.013), engine instruments (0.020)	0.21
	1.99*

* For engines mounted on the wings 0.10lbs. per b.h.p. per engine is to be added, to allow for local structure. This allows for a certain saving of wing weight due to relief afforded by distributed weights.

lb.

Fuel (0.55 pint/b.h.p./hour) = 0.520
Oil (0.018 pint/b.h.p./hour) = 0.021†
Fuel tanks (0.51 lbs./gallon) = 0.035
Oil tanks (0.90 lbs./gallon) = 0.002†

} 0.578lbs. per b.h.p. hour.

† for reserve oil (with tankage) 20lbs per engine must be added to weight of oil, and 2lbs. per engine must be added to weight of oil tanks.

TABLE No. 6.

TWIN-ENGINED TRACTOR TRANSPORT OF FIG. 9 (*a*).

W = 15,000lbs. A = 500 sq. ft. W/A = 30 lbs./sq. ft.
b.h.p. (total) = 1,250. W/b.h.p. = 12 lbs./b.h.p.

Weights:—	lbs.
Structure (25.0 per cent of W)	3,795
Extra for flaps and mass balances	130
Power plant (2.09 lbs./b.h.p.)	2,615
Pilot's seat, flying instruments and electrical equipment	140
Pilot	170
	6,850
Leaving for fuel and oil with tanks, for equipments and for pay load	8,150

Fuel and oil with tanks = 722.5lbs. per hour (full power), plus 44lbs. reserve oil with tankage.

(1) Duration (pilot alone):—

W_E = 7,200lbs. (pilot 170, fuel (964 G.) 7,295, oil (36 G.) 335) = 7,800lbs.

Duration, at 10,000ft., at full speed of 308.9 m.p.h., 11.22 hours, or 3,470 miles.

(2) Passenger transport:—	lbs.
Navigator (160) with seat and instruments (20) ...	180
W./T. equipment	120
14 passengers (160 each), passenger equipment 80lbs.* per passenger, baggage 40lbs. per passenger ...	3,920
	4,220

W_E=8,190lbs. (crew (2) 330, passengers (14) 2,240, baggage 560, fuel (462 G.) 3,500, oil (19) 180)=6,810lbs.

Duration, at 10,000ft., at full speed of 308.9 m.p.h., 5.38 hours, or 1,660 miles.

* 50lbs. common (*i.e.*, insulation, upholstery, heating, ventilating, lavatory, etc.), 30lbs. personal (*i.e.*, seat, rack, etc.).

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SEVENTY-FIRST ANNUAL REPORT OF THE COUNCIL, 1935—1936

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	No. of Members.		Honorary & Life Members.		Suspended.		Total.	
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Members	54	(50)	1	(—)	2	(2)	57	(52)
Associate Fellows	475	(458)	5	(5)	10	(17)	490	(480)
Associate Members ...	116	(98)	—	(—)	4	(11)	120	(109)
Associates	198	(177)	3	(3)	14	(14)	215	(194)
Companions	101	(99)	9	(10)	3	(6)	113	(115)
Founder Members	26	(25)	1	(1)	—	(—)	27	(26)
Students	348	(352)	—	(—)	48	(25)	396	(377)
Temp. Hon. Members ...	—	(—)	29	(21)	—	(—)	29	(21)
	1453	(1393)	71	(62)	84	(76)	1608	(1531)
Less Joint Members ...	28	(28)					28	(28)
	1425	(1365)	71	(62)	84	(76)	1580	(1503)

Donations

The Council have to thank the Air Ministry for the eleventh year in succession for their generous donation of £250 to the funds of the Society, and the Society of British Aircraft Constructors, also for the eleventh year in succession, for their generous donation of £250. These grants have enabled the Society to continue its policy of publishing more and more scientific and technical matter in the Journal and to keep it up to that high standard which has placed it among the leading aeronautical technical journals of the world.

Endowment Fund

The table below gives the progress of the Endowment Fund:—

	£	s.	d.
December, 1926	575	0	0
December, 1927	597	2	0
December, 1928	1,047	18	0
December, 1929	1,077	6	0
December, 1930	1,265	10	0
December, 1931	1,935	10	0
December, 1932	2,196	2	0
December, 1933	9,716	19	5
December, 1934	10,131	14	11
December, 1935	10,895	10	7

The Endowment Fund Trust Deed specifically ensures that every contribution to the fund will be devoted to the provision of the Society's own building and lecture theatre. A sum of at least £50,000 must be raised for that purpose ultimately and the Council urge upon every member to bear the fund in mind. The Society's building has been under constant consideration by the Finance Committee during the year, and they have been studying the ways and means and there is every hope that such a building could be erected on a suitable site at an early date. The final decision will rest upon financial considerations, but a comparatively small sum may influence that decision one way or the other. The acquisition by the Society of its own building and lecture theatre will give members far greater amenities than can possibly be given at present and will add greatly to the prestige of the Society.

Library

The Council have to thank Mr. J. E. Hodgson, Hon. F.R.Ae.S., for the twelfth year in succession for the valuable help and advice which he has given the Society. In addition to his direct help Mr. Hodgson acts as the Society's representative at Council meetings of the National Central Library for Students and the Association of Special Libraries and Information Bureaux, both of which are doing valuable work.

During the year the Library acquired, among other historical matter one of the only two known copies of Henson's original specification with coloured illustrations of his " apparatus for the conveyance of passengers, etc., through the air," and the first known air passport issued in November, 1836, to Charles Green. It was valid for six months and was for a voyage by balloon from London to Holland.

The Society's collection of slides has been very considerably increased during the year and has now reached over 5,000. Many gaps during the year have been filled and the collection is one of the most representative in the world. During the year a master negative has been made of every slide, many of which are unique, and from them prints have been made and classified in albums for ready reference by members. The Council particularly wish to thank all those firms and individuals who have so willingly and generously helped to add to the collection.

The Society's corresponding collection of photographs continues to increase and has now become one of the largest and most interesting pictorial records of aviation in all its branches. Many photographs and slides are lent to members and others for various purposes. The loan of slides for lecture purposes has grown to such an extent that an average, during the winter months, of 250 a week has been reached. No charge is made to members for the use of slides.

In previous years the Council have drawn attention to the use of the Society as a suitable repository for historical items of aeronautical interest, and they hope that members will make use of the Society in this way, so that all members will have an opportunity of seeing such items at the Society's headquarters.

The various indexes which were begun a few years ago have proved their value many times, and have enabled many technical and historical questions to be answered quickly. Members are making increasing use of the Library facilities in this way, and learning to apply in the first instance to the Society for information.

Garden Party

The Society held a Garden Party on Sunday, May 5th, 1935, at the Great West Aerodrome, near Hayes, by kind permission of Mr. C. R. Fairey. It proved to be one of the most successful events of the year and was attended by over 1,500 members and their guests. A full report and list of guests appeared in the Journal for December, 1935. The Council hope to make the Garden Party an annual event.

Wilbur Wright Memorial Lecture

The Wilbur Wright Memorial Lecture for 1935 was delivered before a distinguished audience at the Science Museum, South Kensington, by Mr. D. W. Douglas, President of the Institute of the Aeronautical Sciences, U.S.A., on "The Developments of the Modern Air Liner." The lecture was preceded by the Council Dinner and followed by a Reception. Before the lecture was delivered the various medals and prizes, which have been awarded during the year, were presented. The report of the lecture and the Reception appeared in the Journal for November, 1935.

Lecture Programme

A full list of lectures delivered before the Society, and of the principal lectures delivered before the Branches, were given in the Journal for December, 1935. In addition, the following lectures have been delivered or arranged for during the remainder of the present Session:—

January 6th.—J. E. Hodgson, Esq., Hon. F.R.Ae.S., "Cayley as the Founder of British Aeronautical Science."

January 20th.—Professor W. L. Bragg, F.R.S., "The Theory of Alloy Structures."

February 3rd.—Dr. H. C. Watts, M.B.E., Assoc.M.Inst.C.E., F.R.Ae.S., "Airscrew Development."

February 17th.—Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S., "The Boundary Layer and Recent Developments."

March 23rd.—R. H. Dobson, Esq., "The Jointing of Materials by Welding."

April 20th.—Dr. H. J. Gough, M.B.E., F.R.S., and W. A. Wood, Esq., "New Light on the Strength of Materials Afforded by Modern Physics."

May —.—Wilbur Wright Lecture, D. R. Pye, Esq., F.R.Ae.S. (subject to be announced later).

Lectures before the Branches

January 2nd.—(Yeovil Branch) "The Work of the Engineering Department of the N.P.L.," by Dr. H. J. Gough.

January 2nd.—(Portsmouth Branch) "Commercial Design of Aircraft Wireless Equipment," by Mr. C. B. Carr.

January 7th.—(Bristol Branch) "Aircraft Instruments," by Mr. W. J. Richards.

January 15th.—(Hull and Leeds Branch) "The Compressed Air Tunnel," by Mr. E. F. Relf, F.R.Ae.S.

January 16th.—(Coventry Branch) "Development in Centrifugally Cast Piston Rings for Modern Aero Engines," by Mr. P. R. Twigger.

January 16th.—(Manchester Branch) "The Stratosphere," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

January 16th.—(Portsmouth Branch) "Wing Flaps," by Mr. H. B. Irving, B.Sc., F.R.Ae.S.

January 16th.—(Yeovil Branch) Film Display on "The Development of the Lathe," and three other films.

January 28th.—(Bristol Branch) "Future Research on Air-Cooled Aero Engines," by Mr. A. H. R. Fedden, F.R.Ae.S.

January 30th.—(Yeovil Branch) "Ball, Roller and Needle Bearings and Their Manufacture," by Mr. C. H. Smith.

January 30th.—(Portsmouth Branch) "Flying Controls," by Mr. H. L. Stevens, O.B.E., B.A., F.R.Ae.S.

February 4th.—(Gloucester and Cheltenham Branch) "Ball, Roller and Needle Bearings," by Mr. C. H. Smith.

February 12th.—(Southampton Branch) "The Modern Trend of the Liquid-Cooled Engine Installation," by Mr. Dorey.
February 13th.—(Portsmouth Branch) "Undercarriage Developments," by Mr. G. H. Dowty, M.I.Ae.E., A.F.R.Ae.S.
February 13th.—(Yeovil Branch) "The Practical Use and Maintenance of the Autogiro," by Mr. R. A. C. Brie.
February 18th.—(Bristol Branch) "Aircraft Operating," by Mr. Norman Edgar.
February 18th.—(Gloucester and Cheltenham Branch) "Cooling Problems," by Dr. G. P. Douglas, M.C., A.F.R.Ae.S.
February 20th.—(Coventry Branch) "Variable Pitch Propellers," by Mr. T. E. Beacham, B.Sc., A.M.I.Mech.E.
February 20th.—(Manchester Branch) "Aeroplane Construction," by Mr. R. Chadwick, A.F.R.Ae.S.
February 27th.—(Yeovil Branch) "Development of Fuel and Lubricating Oils," by Mr. Slee.
February 27th.—(Portsmouth Branch) "Duralumin and Elektron," by Mr. S. J. Nightingale.
March 3rd.—(Gloucester and Cheltenham Branch) "Recent Development of Instruments and Electrical Gear," by Major C. J. Stewart, O.B.E., M.I.Mech.E., F.R.Ae.S.
March 11th.—(Southampton Branch) "American Aircraft Design," by Mr. Lobelle.
March 13th.—(Yeovil Branch) "Air Routes," by Mr. Ivor McClure, D.S.O.
March 16th.—(Coventry Branch) "Aircraft Instruments," J. E. Chorlton.
March 17th.—(Gloucester and Cheltenham Branch) "Retracting Undercarriages," by Mr. G. H. Dowty, M.I.Ae.E., A.F.R.Ae.S.
March 17th.—(Bristol Branch) "The 24ft. Wind Tunnel," by Dr. G. P. Douglas, A.F.R.Ae.S.
March 19th.—(Manchester Branch) "Modern Car Production Methods," by Mr. T. G. Bradley, M.I.A.E.
March 19th.—(Coventry Branch) "Type Testing an Aircraft," by Flight Lieut. P. W. S. Bulman, M.C., A.F.C., F.R.Ae.S.
March 27th.—(Yeovil Branch) "The 'Dagger' Aero Engine," by Mr. W. P. Savage, A.F.R.Ae.S.
March 31st.—(Gloucester and Cheltenham Branch) "American Aircraft Design," by Mr. M. Lobelle.
April 23rd.—(Manchester Branch) "Training for a Career in Aviation," by Flt. Lieut. H. F. Jenkins, R.A.F.O.

Students' Section

A report of the activities of the Students' Section for the Session 1934-1935 was published in the December, 1935, Journal. The following is a list of lectures and visits to works arranged for the 1935-1936 Session:—

LECTURES.

October 15th.—"The Commercial Aspect of the Long Range Flying Boat," by Mr. A. Gouge, B.Sc., F.R.Ae.S. Chairman: Major R. E. Penny, O.B.E., A.F.R.Ae.S.
November 19th.—"Tapered Wing Stalling," by Mr. P. P. Nazir, A.F.R.Ae.S. Chairman: Mr. H. E. Wimperis, C.B., C.B.E., F.R.Ae.S.
December 5th.—"The Fundamentals of Boundary Layer Theory, with Some Applications to Aircraft," by Mr. H. Leaderman, B.A., B.Sc. Chairman: Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S.
January 9th.—"Stressed Skin Construction." Informal Discussion. Chairman: Mr. C. H. Jackson, B.Sc., A.C.G.I., D.I.C.

January 28th.—Informal Discussion on "The Technical and Scientific Aspects of the Design, Construction and Flying of Sailplanes." Chairman: Mr. S. Scott-Hall, M.Sc., A.C.G.I., D.I.C., A.F.R.Ae.S.

February 13th.—"The Design and Construction of a Light Aeroplane," by Dr. N. A. de Bruyne. Chairman: Mr. C. H. Jackson, B.Sc., A.C.G.I., D.I.C.

February 25th.—"The Mechanical Testing of Aircraft Structures and Components," by Mr. W. Tye, B.Sc. Chairman: Major C. J. Stewart, O.B.E., F.R.Ae.S.

March 5th.—"Visual Methods of Observing Flow Phenomena," by Mr. W. S. Coleman, B.Sc., A.C.G.I., D.I.C. Chairman: Mr. J. A. G. Haslam, M.C., D.F.C., A.F.R.Ae.S.

March 19th.—"The Monoplane Solution," by Mr. R. C. Abel, A.R.Ae.S.I. Chairman: Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

March 31st.—"The Test Pilot's Job," by Mr. K. Seth-Smith. Chairman: Mr. D. L. Hollis Williams, A.F.R.Ae.S.

April 28th.—"The Application of Aerodynamics to Mechanical Engineering," by Mr. J. L. B. Jones, B.Sc. Chairman: Dr. G. V. Lachmann, A.F.R.Ae.S.

VISITS TO WORKS.

November 30th.—Fairey Aviation Company, Limited, Hayes, Middlesex.

January 18th.—De Havilland Aircraft Company, Limited, Hatfield, Herts.

February 8th.—High Duty Alloys, Limited, Slough, Bucks.

March 7th.—British Aircraft Manufacturing Co., Ltd., and General Aircraft, Limited, Hanworth Aerodrome.

April 18th.—Royal Aircraft Establishment, South Farnborough, Hants.

June 27th.—Aerodynamics Department, National Physical Laboratory, Teddington.

Public Schools' Lectures

For the fifth year in succession lectures have been arranged before the public schools and other educational centres. They have proved to be a most valuable form of propaganda and the constant demand from the schools for these lectures is evidence of their interest and popularity.

Many members have come forward and offered to help by delivering one or more of these lectures, and the Council wish to record their grateful thanks for those who have helped in this way. The demand for lectures, however, still exceeds the supply of lecturers and a number of schools each year have to be refused. It is hoped that members will do what they can to help. There are a series of nine standard lectures, complete with slides, so that the actual preparation involved to the lecturer is reduced to a minimum. Any special lecture for a school can quickly be prepared for a lecturer, when required. Since the lectures were first arranged they have been delivered to audiences totalling over 100,000. Each lecture is arranged to take one hour in delivering.

The following is a list of the standard lectures that have been prepared:—

No. 1. The History of the Aeroplane.
No. 2. The Aeroplane and its Uses.
No. 3. Seaplanes and Flying Boats.
*No. 4. How an Aeroplane is Made and Flies.
No. 5. Training Pilots for the Royal Air Force.
No. 6. The Imperial Air Routes.

* This lecture is a combination of Lectures 8 and 9 for those who want both together. Certain matter and slides given in Nos. 8 and 9 have been omitted so that the lecture takes no longer to deliver.

No. 7. A Trip into the Stratosphere.
No. 8. How an Aeroplane Flies.
No. 9. How an Aeroplane is Made.

In addition to the list published in the December Journal for 1935, the following have been arranged for, or delivered, in 1936:—

January 30th.—Leys School, Cambridge, "A Trip into the Stratosphere," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

January 31st.—Gunnersbury School, "How an Aeroplane Flies," by Mr. P. V. Hoare, A.C.G.I., D.I.C., A.F.R.Ae.S.

February 1st.—Sherborne School, Dorset, "A Trip into the Stratosphere," by Mr. H. J. Penrose, A.F.R.Ae.S.

February 2nd.—Stonyhurst College, "How an Aeroplane is Made and Flies," by Mr. F. R. G. Cook, B.Sc. (Eng.).

February 5th.—Upton College, "A Trip into the Stratosphere," by Mr. E. W. Roberts.

February 8th.—Herne Bay College, "A Trip into the Stratosphere," by Mr. E. W. Roberts.

February 15th.—Eastbourne College, "Some Aspects of Modern Aviation," by Mr. S. Scott-Hall, M.Sc., A.C.G.I., D.I.C., A.F.R.Ae.S.

February 15th.—Mostyn House School, Cheshire, "The Imperial Air Routes," by Mr. F. R. G. Cook, B.Sc. (Eng.).

February 18th.—Frensham Heights School, "How an Aeroplane is Made and Flies," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 18th.—Scottish Society, Walton, "A Trip into the Stratosphere," by Mr. J. T. Morton, A.M.I.Ae.E.

February 21st.—The Technical Institute, Rochester, "Training R.A.F. Pilots," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 24th.—Winchester College, "Some Aspects of Modern Aviation," by Mr. S. Scott-Hall, M.Sc., A.C.G.I., D.I.C., A.F.R.Ae.S.

February 25th.—St. Paul's School, Kensington, "A Trip into the Stratosphere," by Mr. H. T. Winter.

February 25th.—Newport, Isle of Wight, "The History of the Aeroplane," by Mr. T. H. Lloyd.

February 27th.—Northampton Town and County School, "A Trip into the Stratosphere," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 28th.—Willaston School, Nantwich, "A Trip into the Stratosphere," by Mr. F. R. G. Cook, B.Sc.

February 28th.—Haberdashers' Aske's Hampstead School, "A Trip into the Stratosphere," by Mr. C. H. Jackson, B.Sc., A.C.G.I., D.I.C.

February 28th.—Leighton Technical College, "The History of the Aeroplane," by Mr. S. J. Cox, B.Sc.

March 6th.—Clayesmore School, Iwerne Minster, "How an Aeroplane is Made and Flies," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

March 20th.—Barrow and District Association of Engineers, "Aircraft Construction," by Mr. F. R. G. Cook, B.Sc. (Eng.).

March 21st.—Highgate School, "A Trip into the Stratosphere," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

Branches

During the year two more Branches have been formed, one at Portsmouth and one at Southampton and the Council wish to congratulate all concerned on the success of these Branches and their excellent lecture programmes. The increasing employment in the aircraft industry is reflected in the increased membership of the Branches. The Council are well aware that the success of a Branch depends largely upon the Chairman, the Honorary Secretary and the

Committee, and they wish, here, to record their thanks to all concerned for the work they have done to help in furthering the aims of the Society.

The following is a list of Branches:—

Australian:

Chairman: T. D. J. Leech, B.Sc., B.E., M.I.Ae.E.
Honorary Secretary: Philip H. Vyner, A.M.I.Ae.E.
Address: Science House, Gloucester and Essex Streets, Sydney, Australia.

Bristol:

Chairman: Captain F. S. Barnwell, O.B.E., A.F.C., F.R.Ae.S.
Honorary Secretary: H. Yendall.
Address: 76, Redcatch Road, Knowle, Bristol 4.

Coventry:

President: Sir John D. Siddeley, C.B.E., J.P., F.R.Ae.S.
Chairman: Major B. W. Shilson, O.B.E., M.I.Mech.E., F.R.Ae.S.
Honorary Secretary: E. D. Keen, B.Sc., A.M.I.Ae.E.
Address: 8, Wainbody Avenue, Coventry.

Gloucester and Cheltenham:

President: T. O. M. Sopwith, Esq., C.B.E., F.R.Ae.S.
Chairman: H. P. Folland, Esq., M.B.E., F.R.Ae.S., M.I.Ae.E.
Honorary Secretary: F. B. Ford, A.F.R.Ae.S.
Address: St. Margaret, Brockworth, near Gloucester.

Hull and Leeds:

Chairman: Major F. A. Bumpus, B.Sc., F.R.Ae.S.
Honorary Secretary: G. B. Fenton, A.F.R.Ae.S.
Address: Fairview, Brough, Yorks.

Manchester:

President: Sir John D. Siddeley, C.B.E., J.P., F.R.Ae.S.
Chairman: R. H. Dobson.
Honorary Secretary: J. E. A. Waterfall.
Address: 7, St. Andrew's Road, Stretford, Manchester.

Montreal:

Honorary Secretary's Address: Engineering Institute of Canada, 2050, Mansfield Street, Montreal, Canada.

Ottawa:

Honorary Secretary: Squadron Leader A. Ferrier, A.F.R.Ae.S.
Address: 370, Driveway, Ottawa, Ontario.

Portsmouth:

President: A. H. Tiltman, Esq., B.Sc., F.R.Ae.S.
Chairman: F. Radcliffe, Esq., B.Sc., A.F.R.Ae.S.
Honorary Secretary: H. I. Birds, B.Sc., A.F.R.Ae.S.
Address: Park Mount, Kent Road, Southsea, Hants.

Southampton:

Chairman: Wing Cmdr. T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S.
Honorary Secretary: S. Scott-Hall, M.Sc., D.I.C., A.F.R.Ae.S.
Address: c/o Messrs. Supermarine Aviation Works (Vickers), Limited, Woolston, Southampton, Hants.

Yeovil:
President: Sir Ernest W. Petter, M.I.Mech.E.
Honorary Secretary: H. J. Penrose, A.F.R.Ae.S.
Address: Westland Aircraft Works, Yeovil, Somerset.

Cambridge University Engineering and Aeronautical Society (affiliated to the Royal Aeronautical Society):
Aeronautical Section—President: P. Shaw, Esq.
Secretary: A. I. S. Debenham, Esq.
Address: Caius College, Cambridge.

President

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P., was elected President of the Society for the year 1935-1936, at the Council Meeting held on May 14th, 1935.

Vice-Presidents

Mr. H. E. Wimperis, C.B., C.B.E., F.R.Ae.S., and Major T. M. Barlow, M.Sc. (Eng.), M.Inst.C.E., M.I.Mech.E., F.R.Ae.S., were elected Vice-Presidents of the Society at a Council Meeting held on May 14th, 1935, for the year 1935-1936.

Journal

Although there has been an increase in the circulation of the Journal in 1935 over 1934, there has been a considerable increase in the cost. This has been due to two factors, one an increase in the cost of illustrations and the other a decrease in the advertisement revenue. It was noted last year that steps were being taken to increase the advertisement revenue. These steps involved the ending of an advertisement contract which was not accomplished until December, 1935. The advertising is now in the hands of the Society and already there is every prospect in 1936 of the revenue more than doubling itself and placing the Journal on a paying basis.

Finance

The Balance Sheets and Income and Expenditure Accounts of Aerial Science, Limited, and of Aeronautical Trusts, Limited, are published in this issue of the Journal. The form in which the accounts are drawn up shows, for Aerial Science, Limited, an excess of expenditure over income of £564 19s. 6d., as against an excess of expenditure over income of £256 10s. 11d. for the year 1934. This excess has thus increased by £308 2s. 7d. and this is more than accounted for by the following:—

	£	s.	d.
Increase in salaries	196	7	6
Increase in cost of Journal	363	16	2
Slides and photographs	100	0	0
	£660	3	8

The actual position of the Society is more favourable than would appear from the way the accounts are presented. The stock of Journals has again been written down and this writing down will continue until the stock is shown at a purely nominal sum. There is again an increase in the annual subscriptions which must be considered satisfactory. The accounts indicate, indeed, that the Society is in a solvent position and can look forward to a steady consolidation of its resources in the future.

AERONAUTICAL

Balance Sheet,

	£ s. d.	£ s. d.	£ s. d.
Share Capital—			
Authorised—40 Shares of 1/- each	... ...	2 0 0	
Issued—21 Shares of 1/- each	... ...	1 1 0	
Less—Calls in arrear	... ...	1 1 0	— — —
Pilcher Memorial Fund—			
Capital Account—As at 31st December, 1934		99 14 0	
Income Account—Balance at 31st December, 1934 ...	31 3 8		
Add Surplus of Income over Expenditure for year to date	4 0 8	35 4 4	134 18 4
Usborne Memorial Fund—			
Capital Account—As at 31st December, 1934		109 2 5	
Income Account—Balance at 31st December, 1934 ...	33 12 0		
Add Surplus of Income over Expenditure for year to date	3 19 0	37 11 0	146 13 5
Herbert Akroyd Stuart Fund—			
Capital Account—As at 31st December, 1934		688 19 0	
Income Account—Balance at 31st December, 1934 ...	130 18 7		
Add Surplus of Income over Expenditure for year to date	23 18 0	154 16 7	843 15 7
R.38 Memorial Fund—			
Capital Account—As at 31st December, 1934		978 3 10	
Income Account—Balance at 31st December, 1934 ...	311 14 2		
Add Surplus of Income over Expenditure for year to date	36 13 10	348 8 0	1326 11 10
Edward Busk Memorial Fund—			
Capital Account—As at 31st December, 1934		449 6 1	
Income Account—Balance at 31st December, 1934 ...	87 9 11		
Add Surplus of Income over Expenditure for year to date	1 2 10	88 12 9	537 18 10
Wilbur Wright Memorial Fund—			
Capital Account—As at 31st December, 1934		1298 9 9	
Income Account—Balance at 31st December, 1934 ...	95 1 11		
Add Surplus of Income over Expenditure for year to date	14 3 0	109 4 11	1407 14 8
Simms Gold Medal Fund—			
Capital Account—As at 31st December, 1934		250 0 0	
Less—Income Account Deficiency at 31st December, 1934	6 15 6		
Add Excess of Expenditure over Income for year to date	4 13 6	11 9 0	238 11 0
Royal Aeronautical Society Endowment Fund—			
Capital Account—Balance at 31st December, 1934 ...		10131 14 11	
Add Donations received during year		12 7 0	
Entrance Fees received during year		164 17 0	
Profit on Realisation of Investments		160 11 7	
Surplus of Income over Expenditure for year to date		426 0 1	10895 10 7
			£15531 14 3

We report to the Members of Aeronautical Trusts, Ltd., that we have examined the above explanations we have required. We are of opinion that the Balance Sheet is properly drawn up December, 1935, according to the best of our information and the explanations given to us and as

3, Frederick's Place, Old Jewry, London, E.C.2.

21st February, 1936.

TRUSTS, LTD.

31st December, 1935.

	£ s. d.	£ s. d.
Pilcher Memorial Fund—		
£115 6s. 10d. 3½ % War Loan at cost	116 5 0	
Cash at Bank	18 13 4	
		134 18 4
Usborne Memorial Fund—		
£113 3½ % War Loan at cost	114 11 1	
Cash at Bank	32 2 4	
		146 13 5
Herbert Akroyd Stuart Fund—		
£683 1s. 0d. 3½ % War Loan at cost	698 19 0	
Cash at Bank	144 16 7	
		843 15 7
R.38 Memorial Fund—		
£1048 11s. 2d. 3½ % War Loan at cost	1098 18 10	
Cash at Bank	227 13 0	
		1326 11 10
Edward Busk Memorial Fund—		
£284 4s. 2d. 3½ % War Loan at cost	284 4 2	
£217 London Transport 4½ % "A" Stock at cost	199 4 6	
	483 8 8	
Cash at Bank	49 17 6	
Amount due from Aerial Science, Ltd.	4 12 8	
		537 18 10
Wilbur Wright Memorial Fund—		
£1047 6s. 7d. 3½ % Conversion Stock, at cost	800 0 0	
£550 Canada 4 % Stock, at cost	531 10 9	
	1331 10 9	
Cash at Bank	98 15 11	
	1430 6 8	
Less—Amount owing to Aerial Science, Ltd.	22 12 0	
		1407 14 8
Simms Gold Medal Fund—		
£287 16s. 1d. India 4½ % Stock, 1958/68, at cost	250 0 0	
Cash at Bank	20 17 6	
	270 17 6	
Less—Amount owing to Aerial Science, Ltd.	32 6 6	
		238 11 0
Royal Aeronautical Society Endowment Fund—		
Investments at Cost—		
£3504 2s. 8d. 3½ % Conversion Stock	3192 5 1	
£4100 L. & N.E. Rly. 3 % Debentures	3162 6 3	
£3100 L.M. & S. Rly. 4 % Debentures	3162 19 9	
£862 16s. 8d. Manchester 3 % Stock, 1952/55	870 9 8	
	10388 0 9	
Cash at Bank	206 12 5	
Amount due from Aerial Science, Limited	300 17 5	
		10895 10 7
		£15531 14 3

Balance Sheet with the books of the Company and have obtained all the information and so as to exhibit a true and correct view of the state of the Company's affairs as at 31st shown by the books of the Company.

PRICE, WATERHOUSE & CO.

AERONAUTICAL

INCOME & EXPENDITURE ACCOUNTS

Pilcher

	£ s. d.
To Surplus of Income over Expenditure for year carried to Balance Sheet	4 0 8
	£4 0 8

Usborne

To Surplus of Income over Expenditure for year carried to Balance Sheet	3 19 0
	£3 19 0

Herbert Akroyd

To Surplus of Income over Expenditure for year carried to Balance Sheet	23 18 0
	£23 18 0

R.38

To Surplus of Income over Expenditure for year carried to Balance Sheet	36 13 10
	£36 13 10

Edward Busk

To 1935 Award	21 0 0
,, Surplus of Income over Expenditure for year carried to Balance Sheet	1 2 10
	£22 2 10

Wilbur Wright

To 1935 Award	50 0 0
,, Surplus of Income over Expenditure for year carried to Balance Sheet	14 3 0
	£64 3 0

Simms Gold

To 1935 Award	17 12 6
	£17 12 6

Royal Aeronautical Society

To Surplus of Income over Expenditure for year carried to Balance Sheet	426 0 1
	£426 0 1

TRUSTS, LTD.

FOR THE YEAR ENDED 31ST DECEMBER, 1935.

Memorial Fund

	£ s. d.
By Interest on Investments (gross)	4 0 8
	£4 0 8

Memorial Fund

By Interest on Investments (gross)	3 19 0
	£3 19 0

Stuart Fund

By Interest on Investments (gross)	23 18 0
	£23 18 0

Memorial Fund

By Interest on Investments (gross)	36 13 10
	£36 13 10

Memorial Fund

By Interest on Investments (*less* Tax)...	17 10 2
,, Refund of Income Tax	4 12 8
	£22 2 10

Memorial Fund

By Interest on Investments (*less* Tax)	53 14 0
,, Refund of Income Tax	10 9 0
	£64 3 0

Medal Fund

By Interest on Investments (gross)	12 19 0
,, Balance of Expenditure over Income for year carried to Balance Sheet	4 13 6
	£17 12 6

Endowment Fund.

By Interest on Investments (less Tax)	302 6 8
,, Refund of Income Tax	123 13 5
	£426 0 1

AERIAL SCIENCE, LIMITED

Balance Sheet,

	£ s. d.	£ s. d.
Share Capital—		
Authorised—		
20 Shares of 1/- each	1 0 0	
999 Shares of £1 each	999 0 0	
	1000 0 0	
Issued—		
19 Shares of 1/- each, fully paid		0 19 0
Bank Overdraft		609 13 2
Sundry Creditors		631 19 3
Subscriptions and Other Amounts Received in Advance		280 3 6
Income and Expenditure Account—Balance at 31st December, 1934	1636 13 0	
Less—Deficit for the year to date	564 19 6	
		1071 13 6
		£2594 8 5

We report to the Members that we have examined the above Balance Sheet with the Books are of the opinion that the Balance Sheet is properly drawn up so as to exhibit a true and correct information and the explanations given to us and as shown by the Books of the Society.

3, Frederick's Place, Old Jewry, London, E.C.2.

21st February, 1926.

Income and Expenditure Account

Dr.	£ s. d.
To Office Rent, Heating, Lighting and Insurance	559 11 3
,, Salaries	1199 8 4
,, Printing and Stationery	345 19 2
,, Postages, &c....	176 5 1
,, Office Expenses	519 10 9
,, Meetings	110 4 2
,, Dinners and Receptions	115 11 7
,, Journals and Pamphlets (*Less* Sales)	1221 14 5
,, Library Expenses	56 10 5
,, Slides and Photographs	146 13 9
,, Audit Fee	31 10 0
,, Legal Expenses	53 4 9
,, Prizes and Donations	36 19 0
,, School Lectures	21 17 0
,, Subscriptions Written off	17 7 0
	£4612 6 8

(The Royal Aeronautical Society).

31st December, 1935.

	£	s.	d.
Office Furniture, Printed Books, Bindings, Old Prints, etc., at cost, as at 31st December, 1934	453	19	6
Stock of JOURNALS *and other Publications*	350	0	0
Stock of Stationery	13	0	0
Sundry Debtors, including Subscriptions owing	129	8	3
Investments at Cost—			
£1504 15s. 11d. Manchester Corporation 3 °/₀ Red. Consd. Stock, 1952/55 (Market Value at 31st December, 1935, £1542 8s. 4d.)	1518	3	3
Rent Paid in Advance	125	0	0
Cash in Hand	4	17	5
	£2594	8	5

of the Society, and have obtained all the information and explanations we have required. We view of the state of the Society's affairs as at 31st December, 1935, according to the best of our

(Signed) PRICE, WATERHOUSE & CO.

for the Year Ending 31st December, 1935.

Cr.	£	s	d.	£	s.	d.
By Annual Subscriptions				3403	4	0
,, Interest on Investments	25	12	0			
,, Profit on Realisation of Investments	62	3	2			
				87	15	2
,, Donations				500	0	0
,, Examination Fees—*Less* Expenses				56	8	0
,, Balance of Expenditure over Income for year carried to Balance Sheet				564	19	6
				£4612	6	8

Solicitor

Mr. Lawrence A. Wingfield, M.C., D.F.C., A.R.Ae.S.I., continues to act as Solicitor to the Society. Mr. Wingfield gives his advice free on Committees and to the Council on all important legal matters which are raised from time to time, and the Council wish particularly to thank him for the help and time he has so willingly given to the Society.

Honorary Treasurer

This is the ninth year in succession that Major D. H. Kennedy, F.R.Ae.S., has acted as Honorary Treasurer and Chairman of the Finance Committee. His duties have necessitated him giving up a considerable amount of time to the work of the Society, apart from the regular monthly meetings over which he presides to discuss in detail the Society's finances. The financial progress of the Society during the last nine years has largely owed its success to the untiring efforts of Major Kennedy, and the Council wish particularly to place this on record and to thank him for the work he has done and the enthusiasm he has shown on the Society's behalf.

Honorary Accountant

The Honorary Accountant this year completes his eighth year of office. He has been an invaluable member of the Finance Committee and his advice has been greatly to the benefit of the Society. The Council wish to record their thanks for Mr. Smith's constant efforts to help the Society in the way he has done.

Secretary

All who work for or with the Society will pay a tribute to the efficiency and zeal of the Secretary, Captain Pritchard. He is the nucleus around which centre all the activities of our organisation, and it is through his real keenness on the important work with which he is charged that the Society continues to be live and healthy.

Staff

No Council Report would be complete without a tribute being paid to the permanent staff upon whom the real success of the carrying out of the Society's business must ultimately depend. The staff consists of Miss Barwood, in charge in the absence of the Secretary, Miss Voyce, in charge of the book-keeping, Miss Parkes, responsible for a greater part of the clerical work, and Mr. McWilliam, responsible for the Journal advertising, slides and photographs. It is one of the smallest staffs of any corresponding society, and the Council wish to place on record that it is only due to their efficiency and their lively interest in the work of the Society that the administration expenses have been kept well below that of other societies.

The 599th Lecture to be read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

A meeting of the Society was held in the Lecture Theatre of the Institution of Electrical Engineers, at Savoy Place, Victoria Embankment, London, W.C.1, on Monday, December 2nd, 1935. In the chair, the President (Lieut.-Colonel J. T. C. Moore-Brabazon).

The PRESIDENT: Although he was still a young man, Mr. Dowty had started work in the aircraft industry as far back as 1917, when he was associated with Mr. Koolhoven in making the "Bat." Subsequently he had served with the Avro Company and the Gloster Company, and at the moment was Managing Director of Messrs. Aircraft Components, Ltd. He had concentrated his attention on undercarriages, about which he knew more than anybody in England. Undercarriages were very much in evidence—although they ought not to be—and the subject well deserved the attention of all the Society's technical members.

RETRACTABLE UNDERCARRIAGES

BY

GEORGE H. DOWTY, M.I.Ae.E., A.F.R.Ae.S.

Introduction

When invited to give this lecture in a building overlooking London's river, my thoughts wandered back to many pleasant hours spent in watching Nature's graceful handiwork—the common seagull, so familiar to those of us who still have "time to stand and stare" in these hustling days of speed and yet more speed. Wheeling with arched pinions and webbed feet retracted backwards into auxiliary tail organs, these effortless soarers are a vision of to-morrow. What aeronautical engineer, released for a moment from the narrow confines of the drawing board and the workshop, could wish for more profitable day-dreaming than a quiet half-hour spent on London Bridge (shall we say?), admiring the cunning perfection of natural flight? And who could wish for better inspiration for the subject of this paper than a glimpse now and again at Nature's own elegant solution of the undercarriage problem?

Just try for a moment to imagine a flight of pterodactyls across the Pool of London. I am referring, of course, to those of the Shell variety, and not to Prof. Geoffrey Hill's most ingenious experiments with the mechanical species! I have to thank the Shell Company's biological expert for the parasitic nightmare shown in Fig. 1. Viewing the undercarriage structure, I think you will agree that evolution's chief designer must surely have developed an acute aerodynamic conscience quite early in his career, for it is apparent that the long history of animal flight is a relentless war on parasite drag. And the brief history of human flight is but the same theme song, set to the swiftly moving tempo of a mechanical age.

Among the many problems of drag reduction engaging the critical attention of aircraft designers to-day, that parasitic appendix known as the undercarriage stands out, in more ways than one, as probably the most serious single offender still challenging the ingenuity of the designing engineer in his unceasing quest for aerodynamic refinement. Not so many years ago, however, quite a number of designers were openly sceptical of the mechanical feasibility of retracting the undercarriage unit; at least, in such a manner as to make it economically worth while. One suspects that our devotion in this country to the thin-wing biplane had something to do with that particular brand of aerodynamic astigmatism, because it was not until the cantilever low-wing monoplane became an accepted type that the idea of wheel retraction became a fashionable formula.

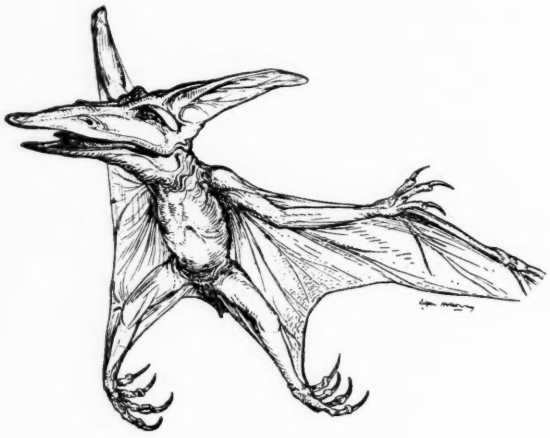

FIG. 1.
Bird or beast? (Shell " Pterodactyl ").

Some Early Sign-posts

On looking back over the post-war evolution of aircraft undercarriages, it is noteworthy (in view of the foregoing remark) that, actually, one of the first practical experiments in wheel retraction was engineered on a thin-wing biplane, the little Martin " K-III " single-seater light plane, built by J. V. Martin, an early American pilot-designer well-known to old habitués of Hendon. This interesting little machine, constructed and flown towards the end of 1918, was a pioneer in the field; and like most pioneers out of step with time. Along with several other novel features, the landing wheels were internally sprung, retracting backwards by manually-operated worm gear, into fairings on the flat-sided fuselage. Fig. 2 shows a three-view arrangement of the machine. Of course, it looks delightfully simple and mechanically straightforward on a job of this size, and I am not pretending that things are always so simple in execution as this on the aeroplane of to-day. For one thing, the narrow track undercarriage would not be tolerated nowadays; the tendency is all for making them as wide as possible, say between one quarter and one fifth of the maximum span. (It is interesting to note that in this country the Beardmore Co. used a similar undercarriage arrangement on their W.B.3 biplane. This machine, designed round a Sopwith Pup fuselage, was also produced in 1918.)

Furthermore, even the next serious effort at undercarriage retraction was not according to the current low-wing formula. The designer of the 1920 Dayton-Wright Gordon-Bennett racer essayed the difficult task of retracting the undercarriage for this high-wing monoplane flush into the recessed sides of an elliptical monocoque fuselage, as shown in Fig. 3. This pioneering effort had a divided type undercarriage, the wheel on each side being mounted on a tubular " V," hinged at the point of attachment to the fuselage shell. The main shock member was attached to the apex of the " V " radius rods at the wheel hub, its upper

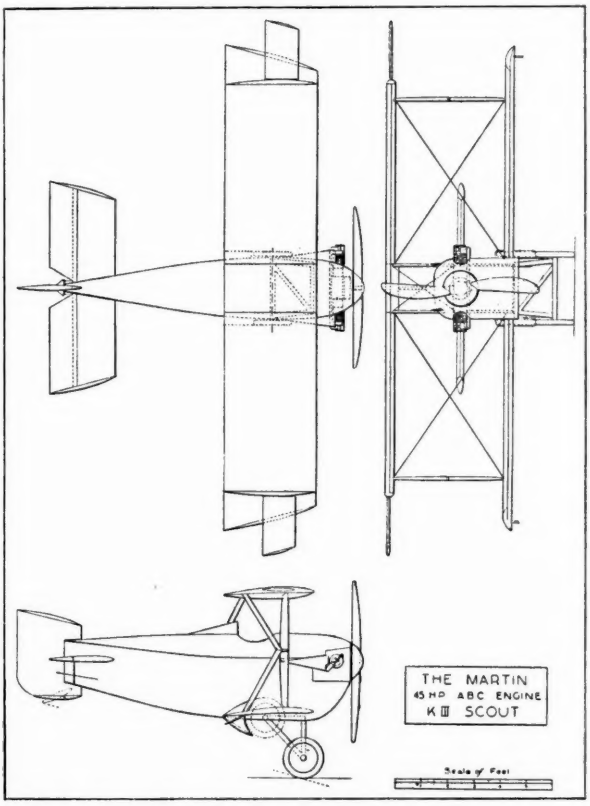

FIG. 2.
Martin " K-III " light plane, 1918.

end pinned to a nut working on a threaded shaft inside the fuselage, the shaft itself being operated by a crank in the pilot's cockpit. Moreover, this hand crank was coupled up to camber flaps on both the leading and trailing edges of the wing, so that the wing camber was automatically increased when the undercarriage was lowered and *vice-versa*. Judged by present-day standards for high-wing layouts, the Dayton-Wright undercarriage would be penalised by the narrow track resulting from such a restricted geometry, but as the fashion cycle revolves from low-wing to high-wing once more, it is likely that modifications of the scheme will return to favour.

As a matter of fact, the Curtiss " BF2C-1 " Fighter biplane and the more recent Grumman Carrier Scout biplane, both in active service with the U.S. Navy, employ a modernised version of this arrangement, the wheels retracting into recesses in the sides of a deeply bellied fuselage; so even the orthodox biplane combination can be accommodated, provided the undercarriage scheme is incorporated *ab initio* in the design project. Fig. 4 illustrates the Curtiss installation, while Fig. 5 is a sketch of Grumman's patent as originally applied to the U.S. Navy " JF-1 " amphibian; and, later, to the Grumman " FF-1 " two-seater scout for carrier operation. And, parenthetically, just as a reminder of British bread cast upon the waters as far back as 1915, Fig. 6 shows a very similar British patent taken out by W. Brierley in that year, although, so far as I am aware, never tried out in flight. In the Grumman amphibian arrangement, the

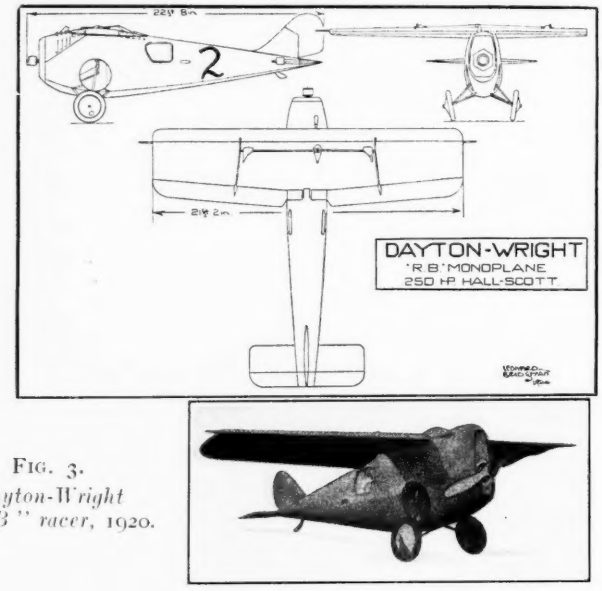

FIG. 3.
Dayton-Wright
" R-B " racer, 1920.

shock absorber strut has an offset hinge, so that under compression the eccentricity tends to keep the strut from " breaking." In retracting, the cables turn the sheave attached to the upper end of the shock strut, thereby turning the upper end inward and " breaking " the strut.

I believe that the next practical application of a retractable undercarriage was the true ancestor of most of our present low-wing monoplane installations. This was the 1922 Verville-Sperry Pulitzer Racer, built by the Engineering Division of the U.S. Air Service to the design of Alfred V. Verville. It was an excellent example of advanced racer design, obviously with an eye to embryo fighter development, as may be confirmed to-day in such designs as the Consolidated " P-30 " two-seater fighter. Figs. 7 and 8 show Verville's design with undercarriage down, and with wheels retracted inboard into wells in the lower surface of the wing. As originally built in 1922, the maximum speed with wheels down was 163 m.p.h., which increased to 191 m.p.h., with the wheels retracted, a jump of 28 m.p.h., or approximately 17 per cent. increase. (Later, in 1924, these figures were increased to 206 and 236 m.p.h., respectively, due to the installation of a larger power plant.) Because the undercarriage structure

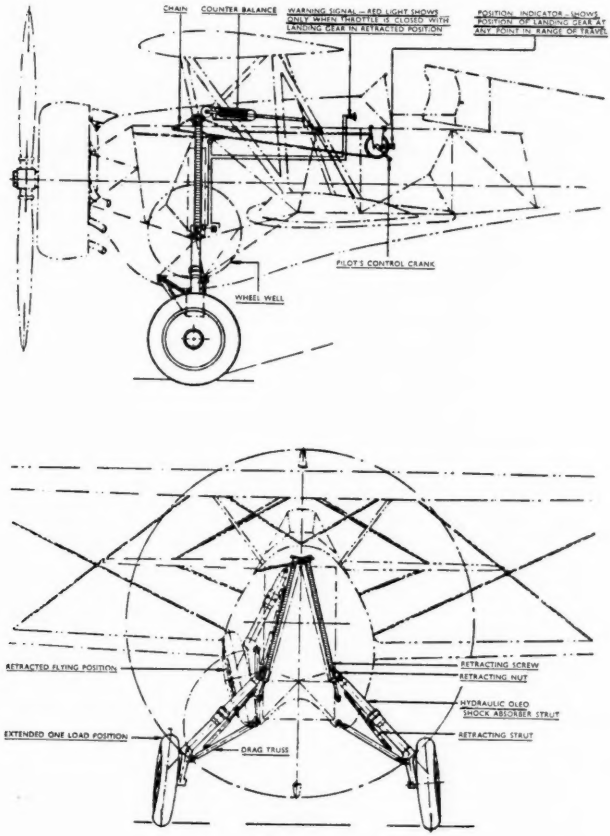
CHAIN
COUNTER BALANCE
WARNING SIGNAL—RED LIGHT SHOWS ONLY WHEN THROTTLE IS CLOSED WITH LANDING GEAR IN RETRACTED POSITION
POSITION INDICATOR—SHOWS POSITION OF LANDING GEAR AT ANY POINT IN RANGE OF TRAVEL
PILOT'S CONTROL CRANK
WHEEL WELL
RETRACTED FLYING POSITION
EXTENDED ONE LOAD POSITION
DRAG TRUSS
RETRACTING SCREW
RETRACTING NUT
HYDRAULIC OLEO SHOCK ABSORBER STRUT
RETRACTING STRUT

FIG. 4.
Curtiss "BF2C-1" fighter retraction gear.

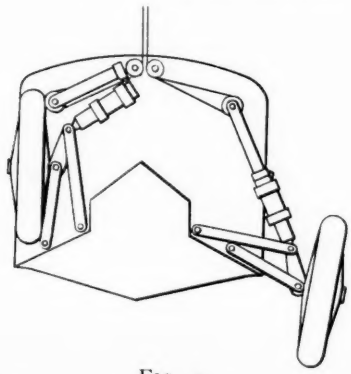

FIG. 5.
Grumman "JF-1" amphibian undercarriage.

was unfaired in the down position, it is probable that the true increase, when assessed on a comparable basis, was not greater than 20 m.p.h. Even so, I think you will agree that this still represents a very notable engineering achievement for that time.

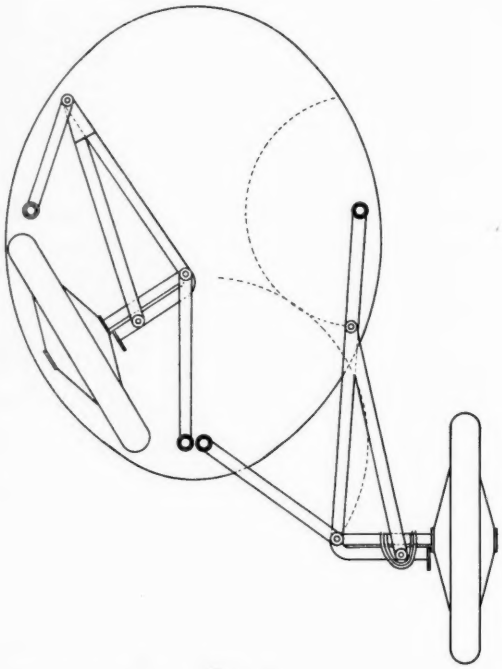

FIG. 6.
Brierley retractable undercarriage patent, 1915.

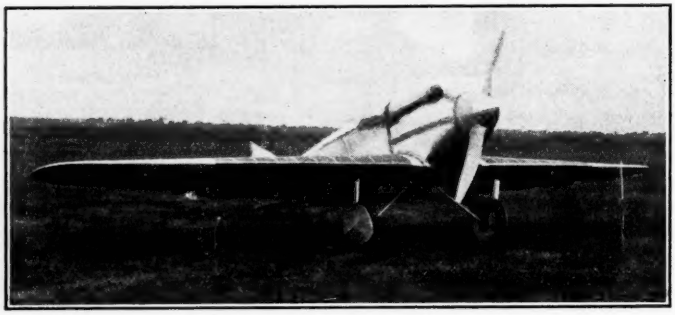

FIG. 7.
Verville-Sperry Pulitzer racer, 1922.

No attempt has been made in the foregoing examples to present a detailed study of retractable undercarriage evolution during the post-war period, since it is the purpose of this paper to describe current practice, with particular refer-

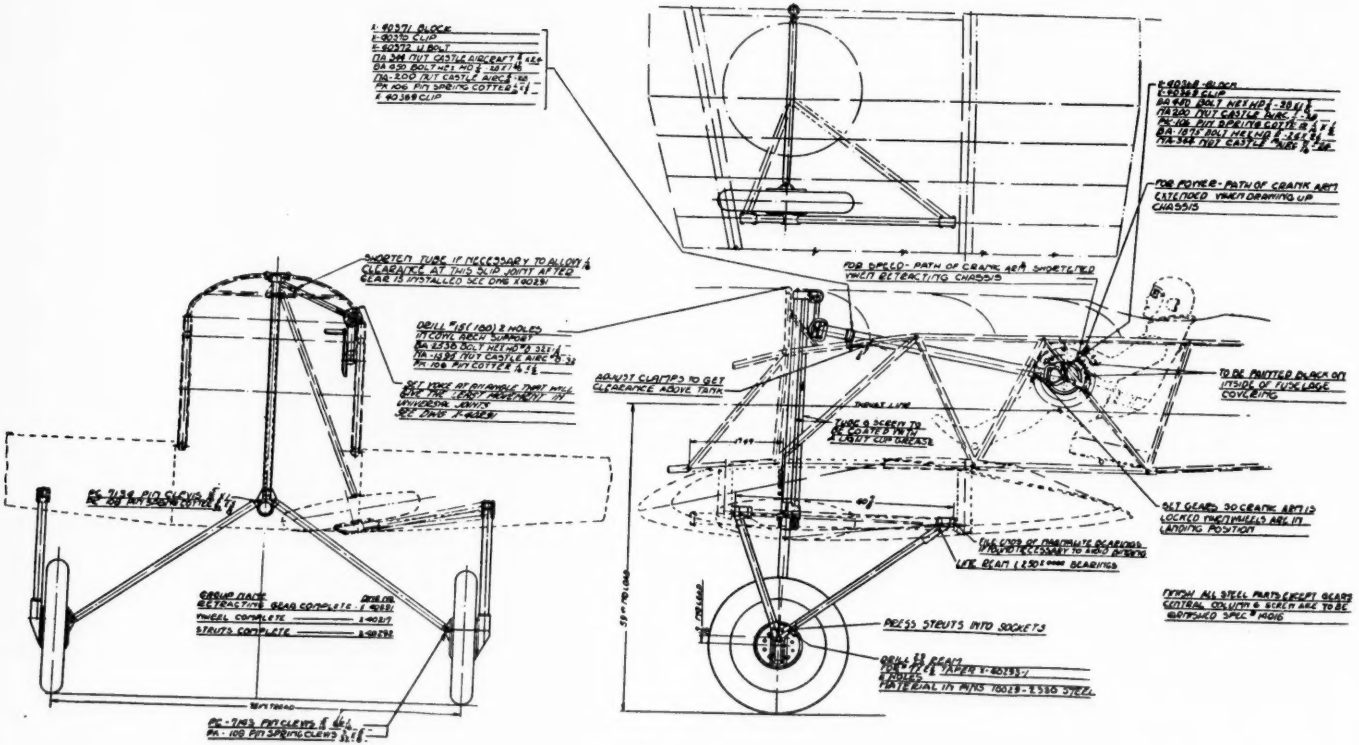
1-60371 BLOCK
1-60370 CLIP
1-60372 U BOLT
1-60389 CLIP
SHORTEN TUBE IF NECESSARY TO ALLOW CLEARANCE AT THIS SOLID JOINT AFTER GEAR IS INSTALLED SEE DWG 760289
DRILL 7/16" (.500) Ø HOLES IN CONN. BOLT SUPPORT
BA 12356 BOLT HEX HD 5/16 x
MA-1698 NUT CASTLE AIRC 5/16
PA 108 PIN COTTER 5/32 x
SET NOSE AT SUITABLE THRUST WHILE TIGHT ASSEMBLY IN UNIVERSAL JOINTS SEE DWG 760289
PC-7134 PIN CLEVIS 5/16 x
PA-108 PIN SPRING CLEWS 5/32 x
GROUP RACK RETRACTING GEAR COMPLETE — 1-60287
WHEEL COMPLETE — 1-60217
STRUTS COMPLETE — 1-58282
PC-7143 PIN CLEVIS 5/16 x
PA-108 PIN SPRING CLEWS 5/32 x
AGAINST CLAMPS TO GET CLEARANCE ABOVE TANK
FOR SPEED - PATH OF CRANK ARM SHORTENED WHEN RETRACTING CHASSIS
FOR POWER - PATH OF CRANK ARM CATALOGED WHEN DRAWING UP CHASSIS
TO BE PAINTED BLACK ON INSIDE OF FUSELAGE COVERING
SET GEARS 30 CRANK ARMS LOCKED FINAL WHEELS ARE IN LANDING POSITION
FOR ENDS OF FRONT AXLE BEARINGS TRIM AS NECESSARY TO ALLOW AIRFOIL
AXLE BEAM 1-60211 BEARINGS
FINISH ALL STEEL PARTS EXCEPT GEARS CONTROL COLUMN & SCREW ARE TO BE CADMIUM PLATED SEE 7 MORE
PRESS STRUTS INTO SOCKETS
DRILL 33 HOLES
MATERIAL 1/4 PINS 760289 - 2330 STEEL

FIG. 8.

Verville-Sperry retraction gear.

ence to the work of my own company during the past year or two. I am aware that the archives of the world's patent offices are the graveyard of many promising undercarriage inventions, some of them stretching back before the birth of the aeroplane itself; and, further, that some form of retracting mechanism has often been used in the past for amphibian aircraft. Generally speaking, however, these amphibian gears have been evolved with the object of obtaining water clearance, rather than the suppression of parasite drag. The examples chosen, therefore, have been briefly sketched with the idea of showing some of the outstanding milestones leading up to present trends in retractable undercarriage design.

Design Requirements

Because the application of a retractable undercarriage at the initiation of a new design project will involve certain considerations not present in the layout of the more conventional fixed undercarriage aircraft, it is worth while outlining some of these special design requirements. The following desiderata should be kept in view during the initial conception of a retractable undercarriage scheme:—

1. The undercarriage in the retracted position should offer no interference with the pilot's location. Particularly in the case of military aircraft, the fuselage cross-section should be kept as small as possible to give the best possible view from the cockpit.
2. The handling of the aeroplane on the ground should be up to the standard of the conventional two-wheel undercarriage with brakes and swivelling tail wheel.
3. Wing or fuselage openings should be closed by means of doors, fairing, etc., on retraction of the undercarriage. Due to take-off requirements, extreme dirtiness in the extended condition should also be avoided, as far as is practicable.
4. When retracted, the undercarriage mechanism should comply with all flight requirements. This needs particular attention when the undercarriage is retained in the retracted position by the operating gear itself, instead of by locks.
5. In both the open and the retracted positions, the undercarriage and mechanism should have the specified flight load factors; *e.g.*, acceleration loads in flight. In any intermediate position, this flight load factor should be at least one half those specified.
6. The retracting mechanism and movement of parts should be such as to permit the carrying of the fuselage design loads, and the geometry of the structure should preferably be determinate and simple.
7. The retracting mechanism should be reliable and incapable of jambing in any intermediate position. Designs that depend on several broken limbs, catches and complicated locking gear should be avoided, despite their theoretical soundness under ideal workshop conditions.
8. The maintenance of the undercarriage should be readily accomplished. The various parts of the retracting mechanism should be readily accessible for inspection, lubrication and repair.
9. The undercarriage must be raised or lowered with reasonable speed, and without undue exertion on the part of the pilot; *e.g.*, a retraction time of 60 seconds and a lowering time of 30 seconds is suggested as a maximum. The operating mechanism should be conveniently placed for the pilot or crew.

10. With hydraulically-operated gears provision should be made for lowering the undercarriage and locking it in the landing position in the event of a burst pipe or failure of a power-operated pump.

11. With electrically-operated gears provision should be made for lowering the undercarriage and locking it in the landing position in the event of a breakdown of the electrical gear.

12. Precautions should be taken to prevent damage, due to over-winding at both ends of the travel, particularly when power operation is employed. With manually-operated systems it should be impossible for the operator to damage any portion of the mechanism if he exerts his full strength to over-wind the gear.

13. It should be possible to correct unequal movement of the two sides of the undercarriage by continuous operation of the gear until both sides are fully home.

14. In the case of power-operated mechanisms, a manually-operated " stand-by " gear should be provided as a safeguard against complete failure.

15. Positive locks should be provided to hold the undercarriage in the landing position. A dead centre mechanism should preferably have an independent lock as an additional safeguard.

16. When locks are provided to fix the undercarriage in the retracted position, precautions should be taken to prevent the lock seizing up, due to mud, rust, or flight deflections, and so rendering it impossible to lower the undercarriage.

17. A suitable visual indicator should be provided on the instrument dash-board to show the position of the undercarriage. Either a mechanical or electrical type may be used and should indicate when the under-carriage is locked for landing and also when it is fully retracted. If the indicator is electrical, the making, not the breaking, of a circuit should indicate that the undercarriage is ready for landing; also the indicators for the " down " locks should preferably be duplicated.

18. The indicator should be operated by the locks themselves to show whether they have gone home. The locks should not operate the indicator until they are fully home.

19. An audible indicator, preferably a buzzer, should be fitted in addition to the visual type. It should be arranged to sound whenever the throttle is less than one-third open with the undercarriage still retracted or not fully down and locked for landing.

Retracting Mechanisms

Retractable undercarriages may be classified in several ways, according to the treatment of the subject. In some respects it is convenient to classify them according to the wheel location in the retracted position, the best location varying, of course, with the type of aircraft. From this viewpoint, the wheels may be retracted into the wings, fuselage, engine nacelles, or external fairings, and all four types of installation are receiving the attention of aircraft designers to-day. For the purpose of the present paper, however, I propose treating the subject rather more from the undercarriage designer's viewpoint, grouping them according to the type of retraction. Although in some cases examined, the motion is a combined one, under this plan we have three well-defined systems, as follows:—(1) Sideway retraction (either inwards or outwards); (2) backward retraction; and (3) forward retraction.

1. *Sideway Retraction.*

Sideway retraction schemes are generally confined to wing type installations, more particularly low-wing monoplanes with thick section cantilever roots, which offer a snug housing for the wheels and retracting mechanism. Indeed, the two considerations, undercarriage-cum-wing arrangement, appear to be closely tied together, since the present popularity of the low-wing formula is due, in some measure, to the inviting feasibility of using it for stowage of the undercarriage. An attractive feature, no doubt, is the short length of chassis structure required, although in the case of inward retraction, it is not always easy to accommodate outboard wing fuel tanks. For that reason some designers have sacrificed a certain amount of wing depth and resorted to outward retraction of the wheels,

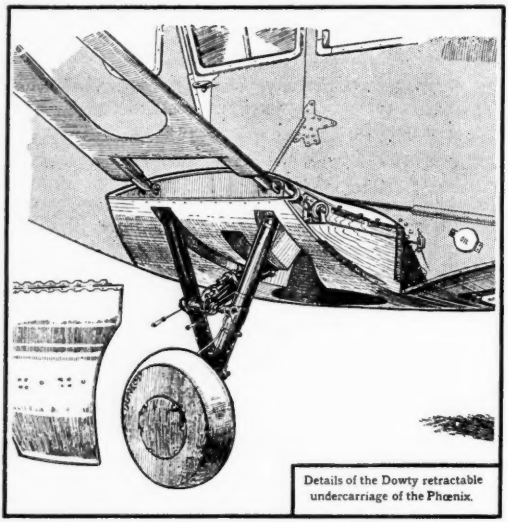

FIG. 9.
Heston " Phœnix " undercarriage.

as seen in the Heinkel " He-70," the British Klemn " Eagle " and the Hendy " Heck " types.

The high-wing sesqui-plane with thickened up lower stub is obviously a further adaptation of the same arrangement, as shown by recent examples, such as the Fairchild " XC-31 " Cargo Transport in America, and the Heston " Phœnix " five-seater recently completed in this country. The " Phœnix " undercarriage, Figs. 9 and 10, employs two opposed hydraulic jacks operating about a central hinge joint of the side bracing member. The latter is divided into two links, or radius rods, the lower link being pinned to the shock strut, while the upper one is pivoted at the fuselage longeron. Simultaneous extension of the two jacks under oil pressure folds the radius rods back upon each other with a " nutcracker " action, and withdraws the wheel and side " V " structure into the stub wing between the two spars. The arrangement is particularly compact in the retracted position, as the retracting strut with its nutcracker configuration folds snugly into the angle made by the side " V " members. This type of folding strut may be applied equally well to fore or aft retraction.

That the sideway type of retraction can also be successfully applied to a single-engined high-wing machine—contrary to current opinion, perhaps—is

evidenced by the extremely neat solution seen in Fairchild's new amphibian boat, type "XA-942," for Pan-American Airways, probably the most efficient single-engined flying boat in operation to-day. From the diagrammatic sketch of the undercarriage geometry, Fig. 11, it will be observed that retraction is accomplished by pulling the upper end of the shock strut inboard by means of a long lead screw and trunnion nut, the latter forming part of a trolley unit sliding along

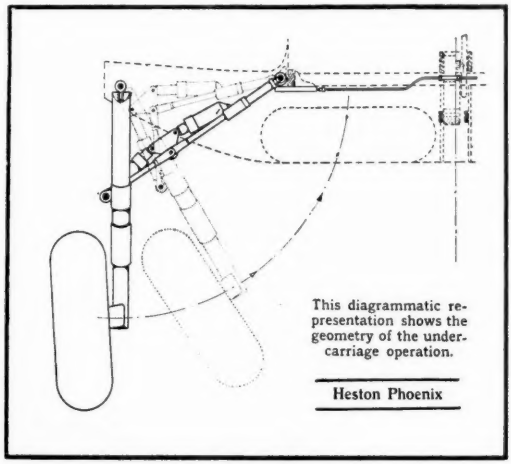

FIG. 10.

Heston "Phœnix" retraction gear.

transverse rails in the spar flange. A backward bias is imparted to the upward and outward movement of the wheel by the side bracing struts pivoting about a downward inclined axis on the hull. The drive of the screw spindle for operating the undercarriage is via a gear box to an electric motor, which also operates a retractable tail wheel, wing tip floats and wing flaps, surely the most complete system of retractable units yet seen in one aeroplane—and a single-engined one at that! Fig. 12 shows this arrangement.

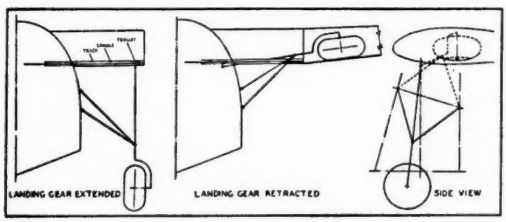

FIG. 11.

Fairchild "XA-942" amphibian undercarriage.

When sideway retraction is employed with conventional two-spar wing systems it is generally necessary to provide this combined motion of the chassis swing, due to the wheels being forward of the front spar. A further desideratum in many cases is that the wheels should lie horizontally when stowed in the wing. In the Fairchild amphibian the wheels rotate slightly around the shock

strut axis during retraction, so that they lie flush with the underside of the wing profile when fully withdrawn. In the Lockheed " Orion " low-wing installation, the problem has been met by arranging the axis of rotation at an acute angle to the chord line of the wing, in such a manner that the hinge point of the rear bracing strut lies outboard of the point of attachment of the shock strut. The resultant movement is a backward, inward and upward swing of the wheels between the wing spars.

Reference to Fig. 13 shows that the Hawker Co. have surmounted this problem in another very interesting manner. The undercarriage is mounted on a cross tube, supported by the front and rear spars, the rear bracing strut being mounted on trunnions to a sleeve which can slide on the cross tube. The top of the rear strut is constrained to follow a short link attached to the top of the rear spar. From the particular configuration shown in the diagram, I think

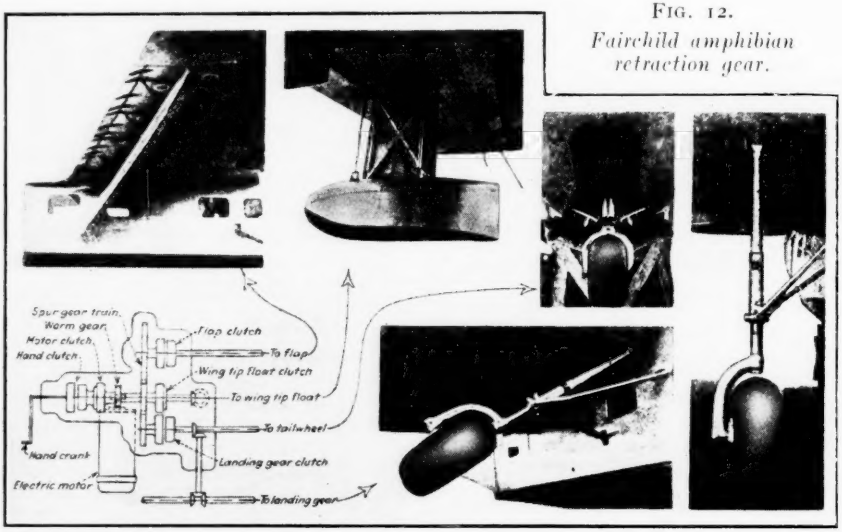

FIG. 12.
Fairchild amphibian retraction gear.

it is clear that when the undercarriage is raised, the wheel will retreat between the wing spars during the sideway movement inboard. The actual operating mechanism consists of a hydraulic jack, which hinges the broken side stay.

With more unorthodox forms of wing design, such as that favoured in the Vultee " V-1A " transport, it is possible to avoid this rearward movement of the wheels. Inspection of this machine, Fig. 14, reveals a deep girder type shear beam, or main spar, situated at about 35 per cent. of the chord, and a smaller rear beam well aft at about 70 per cent. chord, the two members being tied together by the metal covering of top and bottom surfaces. This layout allows sufficient chordal width for housing the small diameter low pressure " air-wheels " between the leading edge and the main spar at the wing root; furthermore, it leaves space clear between the spars for provision of wing fuel tanks in the centre section. The wheels swing inwards without backward bias of any kind, by hinging on a true fore-and-aft pivot tube slung between the leading edge and the main spar. The wing carries an automatically operating fairing shield which completely closes the wheel well, leaving a perfectly flush wing profile

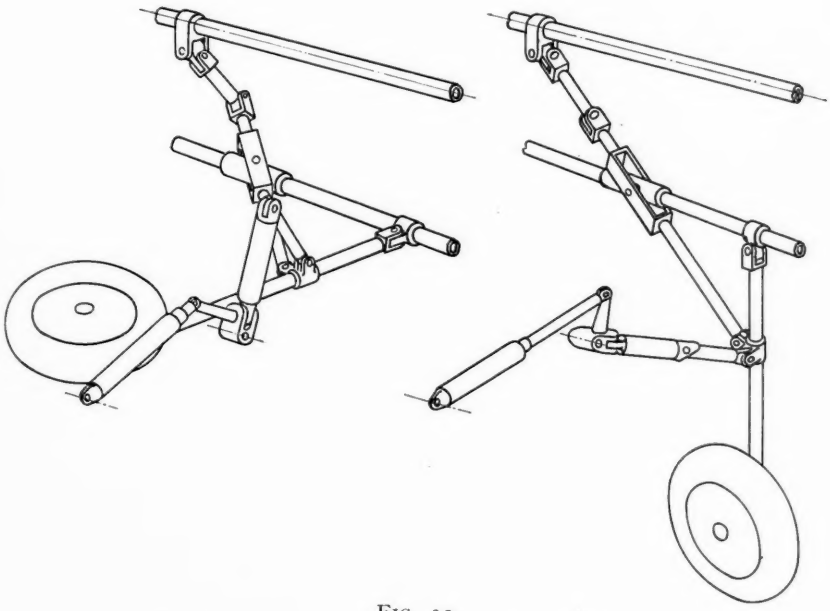

FIG. 13.
Hawker undercarriage: Inward-backward retraction.

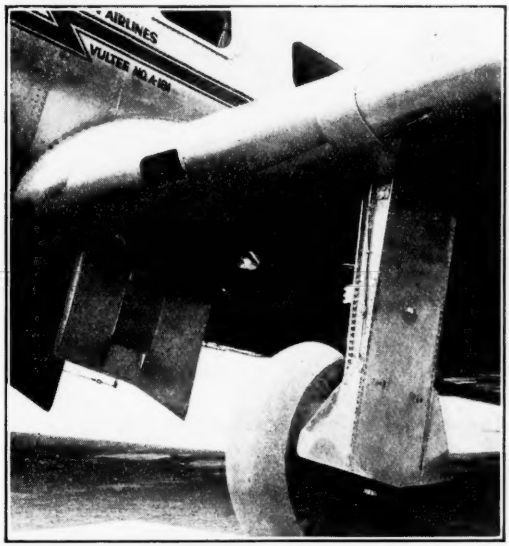

FIG. 14.
Vultee "V-1A" transport undercarriage.

when retraction is completed. At the same time, a single cable, running from the undercarriage back through the fuselage to the tail wheel, partially retracts the latter by taking up the wheel travel into the tail cone.

Retraction of the undercarriage, Fig. 15, is by a worm shaft running transversely across the centre section and geared to the undercarriage legs by a toothed quadrant, or worm wheel sector, attached to the upper end of the leg at the pivot tube. The worm shaft is driven by an electric motor, operated by throwing a toggle switch, no other attention being necessary by the pilot. The same motor also operates the wing flaps, either independently or in conjunction with the undercarriage by means of a small sliding gear transmission. An emergency manual control is also provided, as well as the usual signal and warning devices to indicate the position of the wheel. With power operation, the undercarriage is raised and lowered in about 15 seconds each way.

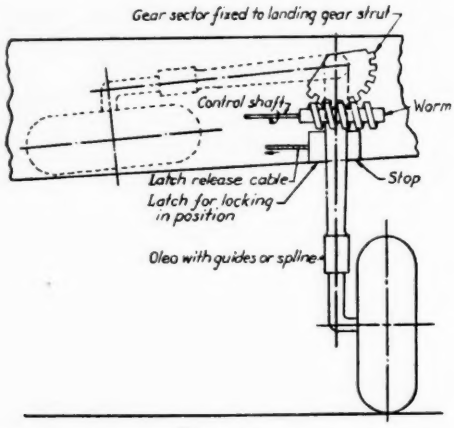

FIG. 15.
Vultee type retraction gear.

The straightforward geometry, together with the single box type cantilever leg, undoubtedly makes for an extremely neat mechanical solution and a very robust construction. Confirming the latter point, I have been told that this machine has made a successful forced landing with the wheels less than halfway down; the damage, indeed, was so slight that after jacking up and running the gear up and down a couple of times, the machine took-off from San Francisco and returned to the works in Los Angeles for further inspection. Some of my friends who have seen the Vultee machine in daily operation in the States are quite eulogistic about the clever engineering design back of it, and from all accounts I am led to believe that the Vultee undercarriage is one of the soundest in its class.

Before passing on to fore and aft retraction schemes, I should like to illustrate one more example of the sideway retraction type, since the scheme appears to have some good mechanical features, and being cable-operated it shows promise of a light installation when used on small aircraft where hand operation would be feasible. The arrangement shown in the next diagram, Fig. 16, is due to the Engineering Division of the U.S. Air Corps. The pull of the cable on retraction is changed from the slide to the undercarriage proper to the best advantage as the slide pulley passes the fixed pulley. Thus the first pull of the retracting cable breaks the slide loose and as the slide passes the fixed pulley, the cable

leaves the slide pulley and the undercarriage is lifted directly, thereby giving a straight and direct pull on the chassis. This arrangement requires a fairly thick wing section, but reduces mutilation of the wing profile in the extended position to the locality of the wheel well.

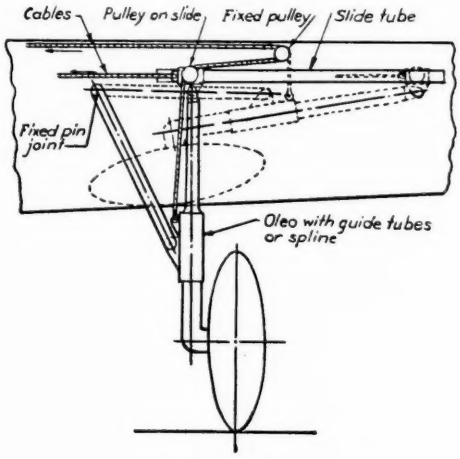

FIG. 16.
U.S. Air Corps (Engineering Div.) retraction gear.

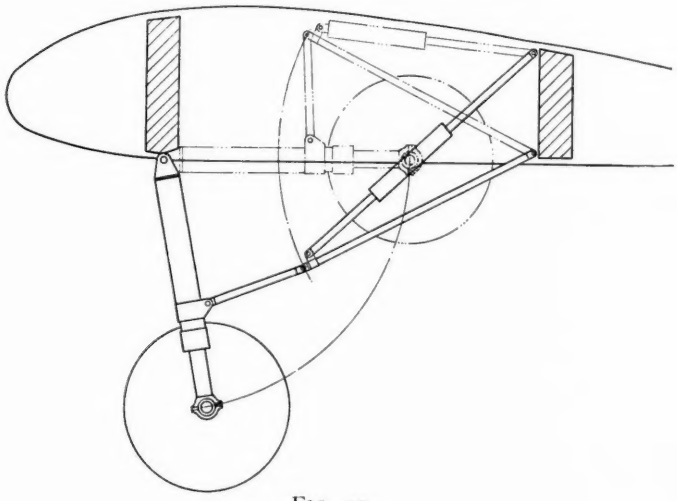

FIG. 17.
Airspeed "Courier" undercarriage.

2. *Backward Retraction.*

As one of the first practicable gears of the backward retraction type in this country, the Airspeed "Courier" installation deserves special mention; indeed, it is but fair to add that the "Courier" set the domestic fashion in retractable

undercarriages nearly three years ago. Fig. 17 shows that the Airspeed designers have achieved a very simple and light gear by making use of a telescopic strut, or jack, to " break " the rear bracing strut and fold the wheels halfway into the wing profile between the front and rear spars. The chassis itself consists of a divided type axle, pinned at its lower end to the usual side " V," the front member of which is a shock absorber strut hung from the front spar. The rear brace of the " V " is divided into two links hinged together near the centre of the strut, the upper link acting as a radius rod pivoted at its point of attachment at the bottom of the rear spar, while the lower link is pinned to the bottom of the shock absorber unit near the wheel.

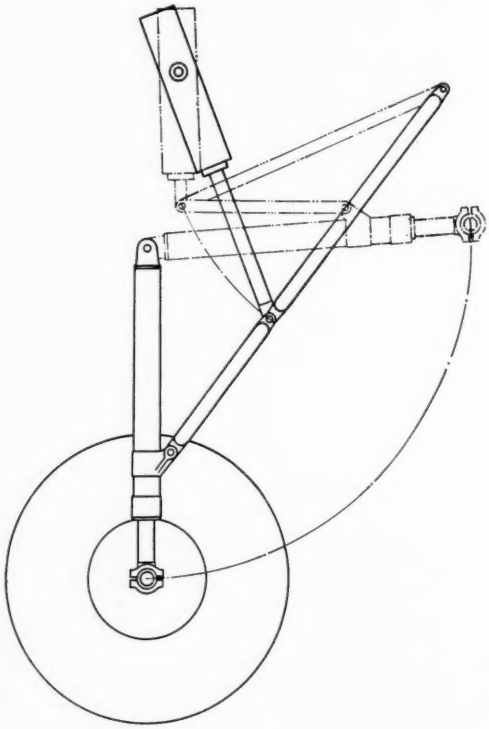

FIG. 18.
Backward retraction gear.

Incorporated in the telescopic strut is an oil cylinder and piston rod, by means of which the strut is compressed or extended the upper end being pivoted to the top of the rear spar, while the lower end is attached to the upper link of the rear strut near the hinged joint. To raise the undercarriage, the oil is exhausted from above the piston and pumped in below so that the telescopic strut is shortened. This " breaks " the hinged joint in the rear brace and lifts the upper link into the wing profile, the lower link pulling the wheel backwards and upwards into faired recesses in the underside of the wing. A point worth noting is the method of locking the rear bracing strut in the extended position by arranging the two links slightly over dead centre.

Strictly speaking, however, the idea of retraction by means of " breaking " a radius rod (or equivalent structural member) at some intermediate point in its length is of very early date; certainly of pre-war vintage, at any rate, for as far back as 1911, both Glenn Curtiss, in America, and Blanc, in France, produced designs using this feature for undercarriage retraction. Some recent designs evolved by my own company, Aircraft Components, Ltd., applying this idea to wing type installations, may be of interest to aircraft designers.

Fig. 18 illustrates a layout very similar to the Airspeed design in that the rear bracing strut is composed of two links hinged together at the centre, the strut being broken by the action of the vertical jack and piston rod, which lifts the wheel in a backward direction between the wing spars. The lifting jack is arranged to oscillate between trunnions carried on brackets from the front spar and the general arrangement is quite simple and straightforward. This scheme is also suitable for engine nacelle installations.

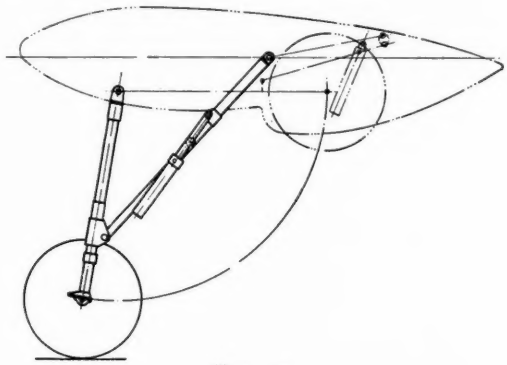

FIG. 19.

Backward retraction gear

Fig. 19 shows another system of " breaking " the rear strut. This is accomplished by placing the jack across the hinge joint in such a manner that the piston rod is pivoted to the upper link on one side of the centre hinge, while the jack cylinder is fixed by trunnions to the lower link on the other side of the hinge. The line of action of the jack being offset from the hinge pin when the rear strut is extended, upon compression of the jack there is a positive couple tending to fold the upper and lower links back upon each other. A feature of this geometry is that the moment of the jack about the hinged joint increases progressively during hoisting of the chassis so that in the retracted position the moment reaches a maximum and the driving effort tapers off. In this scheme the wheel retreats aft of the rear spar and for that reason it is probably more suitable for engine nacelle installations rather than the single-engined low-wing machine.

Fig. 20 shows yet another scheme for breaking the rear bracing strut. Because of space economy, necessitated by the particular aircraft structure employed, the jack is mounted more or less in line with the rear strut. The ram is connected to the upper link of the rear strut by means of a connecting rod attached to an offset pin on the link. Extension of the ram pulls up the upper link and folds the lower link back upon it, thus raising the wheel.

Fig. 21 shows a scheme having the jack mounted through the hinge joint of the rear bracing strut, which is divided into upper and lower links. The ram of the jack is connected to offset pins on these links via short connecting rods. When the jack is extended, the connecting rods close the links back upon each

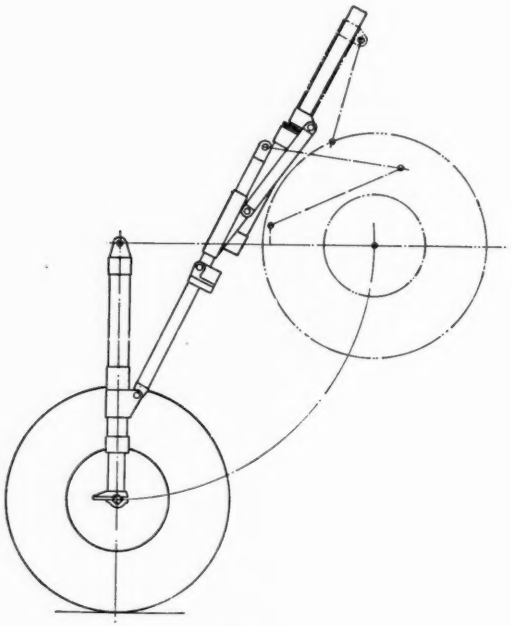

FIG. 20.
Backward retraction gear.

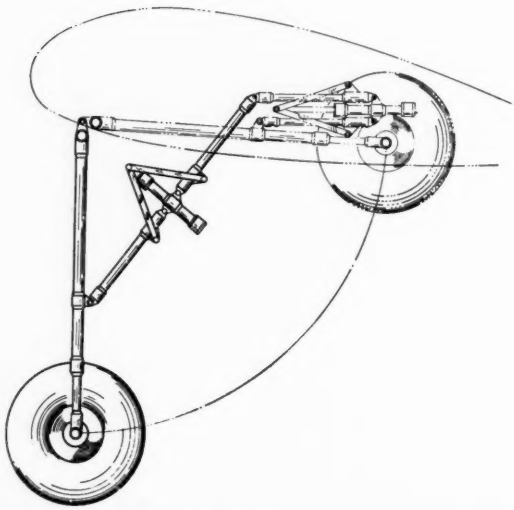

FIG. 21.
Backward retraction gear.

other, thereby raising the wheel backwards between the wing spars. This layout also might possibly be adapted for sideway retraction.

Fig. 22 shows a solution for a multi-spar wing system, the jack being disposed horizontally between the shear beams. The rear bracing strut is hinged at its

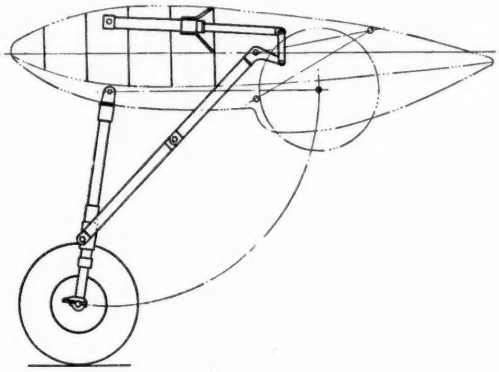

FIG. 22.
Backward retraction gear.

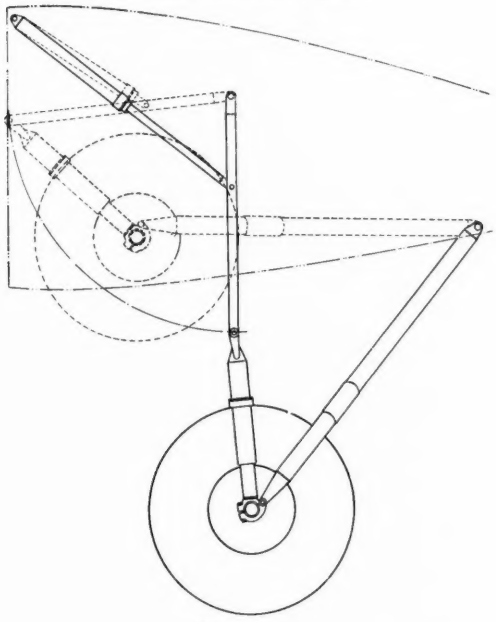

FIG. 23.
Douglas "DC-2" transport undercarriage.

mid-point, the upper link of which rotates on a cross shaft to which a lever is keyed, the lever itself being connected to the jack by a short link. When the jack is compressed the upper and lower links of the rear strut fold together

and the wheel is withdrawn towards the rear portion of the wing. By virtue of the jack being rigidly fixed, the movement of the chassis is positive on both its upward and downward paths. A further point is that with the undercarriage extended, the rear bracing member is straight and no load is carried by the short connecting link or jack.

3. *Forward Retraction.*

Forward retraction does not appear to have received the same amount of attention from designers, probably because backward retraction schemes generally offer a more simple solution due to the presence of a rear bracing member and

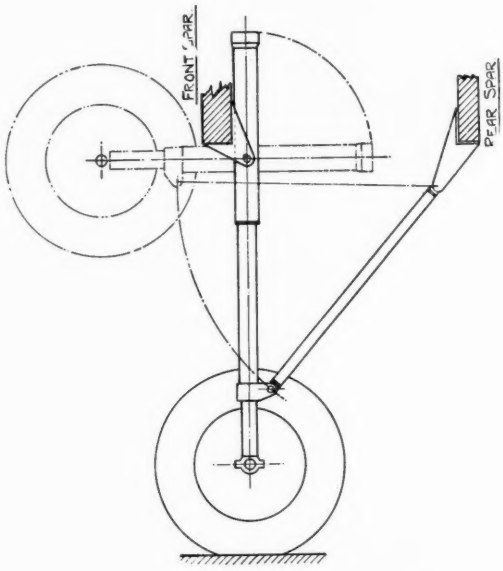

FIG. 24.
Forward retraction gear.

the ease with which it may be " broken " and folded. Except in the case of wing nacelle combinations it is not usually possible to employ a forward bracing member, hence forward retraction is generally confined to this type of installation. Probably the best known example of forward retraction in a wing nacelle is the Douglas " DC-2 " transport. The Douglas undercarriage, illustrated in Fig. 23, employs a " broken " front stay, but it is chiefly remarkable on account of the low weight achieved, which I understand is less than 5 per cent. of the gross weight of the aircraft.

Many other designs for forward retraction obtained without use of a broken front member have been evolved by our company during the past year or so. All of these designs feature a hydraulic jack in some form or the other, either hand or power operated, and it is quite possible that several of them will be found suitable for certain forms of single-engined wing arrangements, as well as the more obvious possibilities of engine nacelle installation. The designs shown in Figs. 24-29 are a selection from some of our recent undercarriage schemes.

Fig. 24 shows a system of retraction which does not depend upon broken limbs of any kind; in fact, this scheme is the very essence of mechanical sim-

plicity. The undercarriage structure conforms to normal practice with the usual side " V " comprised of front shock strut and rear brace pinned to front and rear spars respectively. The upper part of the shock strut, however, is housed in another cylinder pivoted to the rear face of the front spar. This cylinder acts as a jack, the upper part of the shock strut forming the piston, or ram. Retraction is carried out by pumping oil below the piston, thus shortening the shock strut and lifting the wheel. A worth while feature is the balancing effect obtained by the shortness of the C.G. arm from the pivot during the raising operation.

Fig. 25 is similar to the above in some respects, in that it employs a vertical lifting jack mounted on the rear face of the front spar. The shock strut is attached to the lower end of a vertical link, anchored at its upper end to the

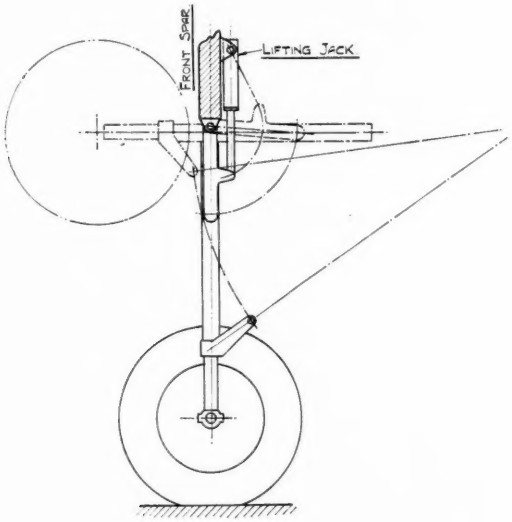

FIG. 25.

Forward retraction gear

lower flange of the front spar. The ram of the jack is pinned to the link via a short horizontal crank, so that when the jack is compressed, the link swings backwards, carrying with it the upper part of the shock strut. Since movement of the lower end of the shock strut must conform to the path of the rear bracing member, the wheel will be lifted to a retracted position forward of the front spar, as shown.

Fig. 26 shows a scheme developed by the Armstrong-Whitworth and Avro Companies. The upper end of the shock strut is pinned to a vertical link to which is attached a spur wheel meshing with an internally toothed ring. The ram of the jack is pinned to a curved link formed on the toothed ring, so that extension of the jack forwards rotates the link through 180°, thereby lifting the shock strut and raising the wheel to the position shown.

Fig. 27 shows a scheme in which all broken limbs are again avoided. The rear brace is pinned to the wing or nacelle structure at a lower point than the upper attachment of the shock strut. The shock strut is pinned to a shackle forming one end of a horizontal jack, the jack itself being supported at both

ends. Retraction is effected by movement of the jack aft, lifting the wheel almost vertically and so taking up a very small stowage space.

Fig. 28 shows a design suitable for a wing nacelle combination employing a tubular monospar construction. The arrangement is similar in all essential respects to Fig. 27, hence it will not be described further.

Fig. 29 is a further variation of the same principle. In this particular arrangement severe limitations were imposed on the undercarriage attachment

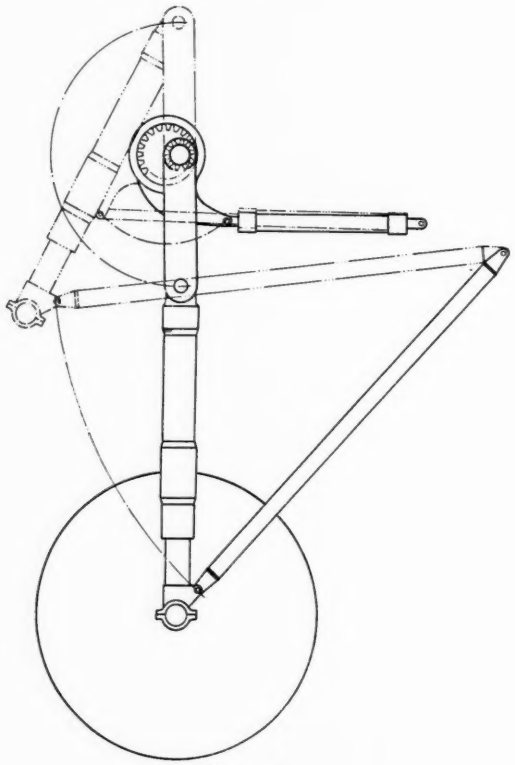

FIG. 26.
Forward retraction gear.

points and the position of the wheel when retracted. The only apparent solution lay in the use of two jacks giving a differential movement, the upper attachment of the shock absorber sliding aft, while the upper attachment of the rear stay slides forward and slightly downwards. Such an arrangement has the advantage of space economy, thus facilitating retraction with a mono- or multi-spar wing system.

Apart from the elimination of all " broken " members and the merit of space economy, perhaps the chief virtue of using a fixed horizontal jack in many of the designs described above is its self-locking action in the extended, or landing, position. For minimum operating loads during retraction it is desirable that the jack should be directly loaded; that is, the loads should come directly on the ends of the ram and in line with the cylinder. From the safety point of

view, with undercarriage extended, the shock strut should lie at right angles to the jack, so that landing loads do not tend to make the ram collapse. Further discussion of locking systems is given under the appropriate heading.

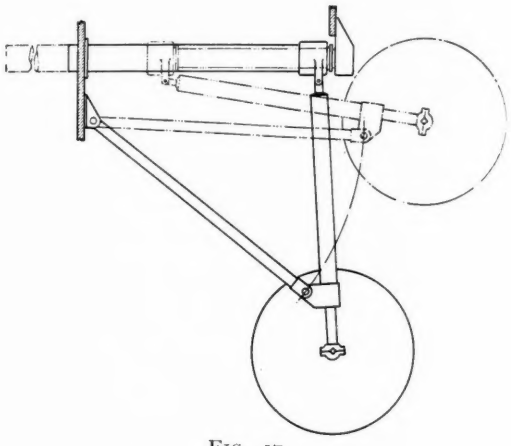

FIG. 27.
Forward retraction gear.

The pros and cons of the different systems of retraction are not strictly within the province of the undercarriage designer. I should hesitate to lay down any hard and fast rules because in the end so much depends upon the aerodynamic

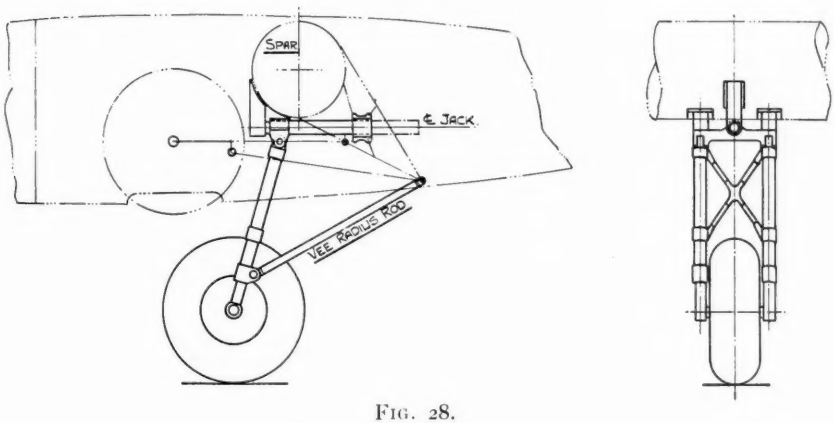

FIG. 28.
Forward retraction gear.

concept and structural layout favoured by the aircraft designer. It seems certain, however, that with single-engined aircraft, total suppression of the undercarriage drag can only be effected by a sideway system of retraction. In this type of aircraft, forward or backward retraction is invariably obtained at the expense of partial exposure of the wheels or fairings and some extra drag, although the

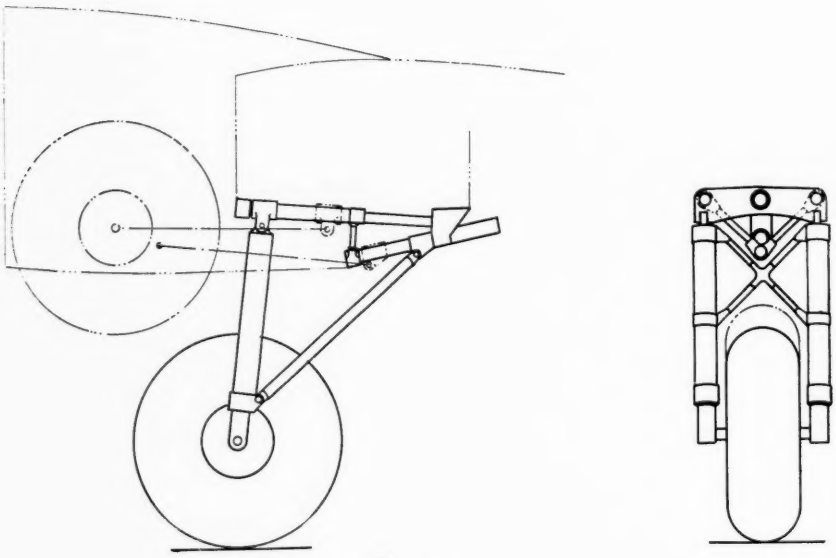

FIG. 29.
Forward retraction gear.

difficulty of covering the wheel and strut openings in the wing is generally simplified. The story is very different, however, in the case of multi-engined machines with undercarriages mounted directly below outboard engine nacelles. In this type of aircraft, either forward or backward retraction is undoubtedly the most straightforward method, as witnessed by the numerous examples already described. A further point scored by forward retraction, at any rate, is the ability to make a successful " abdominal " landing with the wheels up. I am informed on good authority that this actually happened twice with the prototype of one well-known American transport, much to the satisfaction of the transport

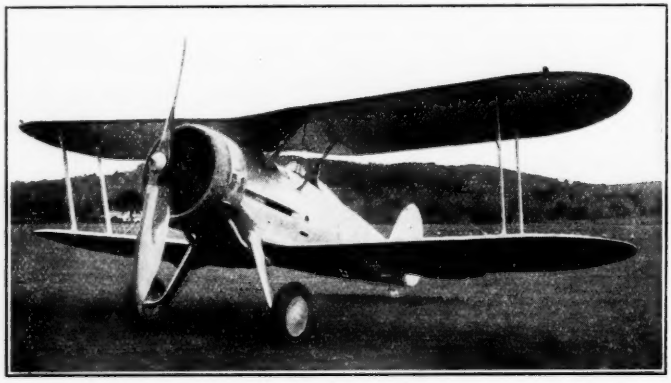

FIG. 30.
Gloster " Gladiator " with cantilever undercarriage.

operators who were thus given advance proof of such an excellent emergency quality.

Another argument sometimes cited against sideway retraction is the detrimental effect on take-off caused by mutilation of the under surface of the wing when the wheels are extended. Vultee, by the way, has very cleverly adapted the open wheel wells to some practical advantage by housing the wing landing lights within these recesses, as shown in Fig. 14. N.A.C.A. full-scale research (reference Technical Note No. 456) on a Lockheed " Altair " indicates that the presence of the wheel openings had a negligible effect on the lift/drag ratio at the take-off, the difference being only of the order of 2 per cent. Far more important, indeed, is the drag of the unfaired chassis in the extended position. In the case of a very clean high speed type, such as the " Altair," retraction of the undercarriage halves the minimum drag of the complete machine, hence even at the optimum take-off speed, the effect on performance must be appreciable. The point is worth stressing because most designs of retractable gear suffer from extreme " dirtiness " in the extended position and there appears to be scope for some improvement in that direction.

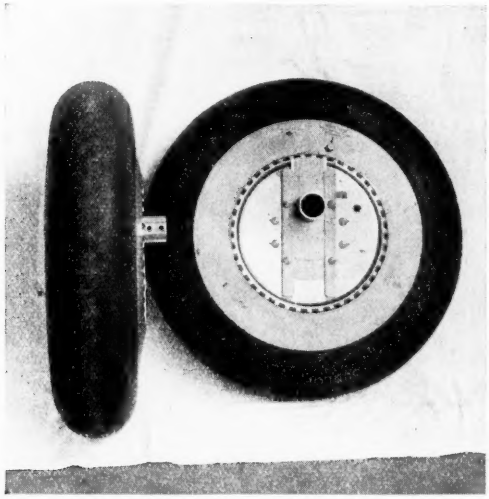

FIG. 31.
Dowty internally-sprung wheel.

This question of " dirtiness " leads us to another angle in our attack upon parasite drag. Recent systematic research by the N.A.C.A. in America (reference Technical Report No. 485) has shown the possibility of designing very low drag undercarriages of the faired cantilever type, such undercarriages accomplishing a large percentage of the gain obtainable from the use of the retractable type. It is not surprising, indeed, that the single cantilever strut, anchored at the body or wing, is shown to have considerably less drag than the more conventional non-retracting undercarriage. What is a little surprising, however, is the slow adoption of the cantilever principle in this country until quite recently, because the internally-sprung wheel was originally designed with precisely that object in view some seven or eight years ago. The Gloster " Gladiator," seen in Fig. 30, is a recent example of the cantilever trend employing a streamlined

internally-sprung wheel developed by our company. Two views of the wheel itself are shown in Figs. 31 and 32.

The further question of whether the fixed cantilever undercarriage is more economical in the engineering sense than a retractable type cannot be answered off hand, since clearly the problem cannot be isolated from many other design factors which influence the designer's choice. Apart from aerodynamic considerations, the economic side of the picture from the financial angle is bound to influence the undercarriage story to some extent, especially on the smaller civil types. It cannot be denied that retracting mechanisms and their operating systems are an added source of expense, both in first cost and upkeep, hence the simplicity of the cantilever structure is attractive. This much, at any rate, can be safely stated; if retraction cannot be obtained in a mechanically straight-

FIG. 32.
Internally-sprung wheel: Shock unit.

forward manner and without expensive mutilation of other parts of the aircraft structure, it is obviously more economical from all points of view to resort to a cantilever construction.

Before leaving the subject of retracting mechanisms, I should like to advance a plea for the pooling of patents by British constructors, somewhat on the lines of the reciprocal arrangement which has operated so successfully for a number of years in the States. The legal position in this country at the present time is extremely complicated and undoubtedly detrimental to the individual interest of all concerned. It is more than likely that many of the mechanisms discussed may be the subject matter for patents at home and abroad. Certainly, in a large number of these examples, my company hold a proprietary interest, but if I have inadvertently trespassed upon another man's domain, I hope I shall be forgiven in the interests of our joint aim, which is surely to advance the engineer's art and to improve the breed of British aircraft.

Operating Systems

Retracting mechanisms may be operated either manually or by power systems, according to the type and size of aircraft. Manual systems may be classified into two main groups, mechanical and hydraulic. The mechanical group may be further sub-divided according to the form of mechanism; *e.g.*, cable and pulley, screw and nut, worm and other gears, all of which have been used for retraction schemes at some time or another. Power systems are even more diverse, many of them being of recent birth and, therefore, still in the experimental stage. Some of the various ways in which power can be applied to drive the retracting mechanism are by: Electric motor and mechanical coupling; electric motor and hydraulic pump; aero engine coupling to hydraulic pump; compressed air motor and hydraulic pump; and other pneumatic systems.

The choice between manual or power operation depends in the first place upon the type—and more particularly the duty required—of the aircraft. With the possible exception of small primary trainers, it seems practically certain that hand operated gears will not be tolerated on military aircraft where the pilot's duties, especially in single-seater fighters, are already manifold. The thought of hand pumping or cranking during formation take-offs and landings is altogether too alarming! Manual operation seems restricted, therefore, to the smaller types of civil aircraft where the time allowed for raising the gear is not such a critical factor, and the weight of undercarriage to be lifted is not prohibitive, or unduly fatiguing to the pilot. British airworthiness requirements do not yet call for a maximum permissible time for raising or lowering the undercarriage, although I understand that the U.S. Dept. of Commerce require that a gear should be lowered in 60 seconds or less. From the safety point of view this seems too liberal and I am going to suggest that retraction should be effected in a maximum of 60 seconds, while lowering and locking home ready for landing should not exceed 30 seconds, all told.

On the basis of our own tests, we have found that the average operator is able to exert, without undue effort, a force of 15lb. to a hand lever, making 60 single strokes (*i.e.*, 30 double, forward and return, strokes) of 12ins. travel, over a period of one minute. Assuming a mechanical efficiency of 70 per cent. for the system, we have at our disposal for manual operation, a total useful work of $15 \times 60 \times 12 \times 0.70 = 7,560$in./lb. as a maximum available for lifting the undercarriage. If we assume further that retractable undercarriages weigh between 5 and 6 per cent. of the gross weight (W) of the aircraft, and that a rough and ready rule for the height of lift (H) in inches is given by $20 + W/400$, we arrive at a machine between 4,200 and 4,800lb. gross weight, as the limiting case for manual operation. This estimate, of course, is only a very wide approximation, since both the height of lift for retraction, and the structure weight ratio depend on the individual undercarriage design; the weight range quoted above, for example, will be considerably lower down the scale for high-wing retractions, since the undercarriage lift is greater.

For manual operation, a hydraulic system is superior, in my opinion, to a mechanical one. In the first place, a more flexible installation is possible, since the oil lines from the cockpit to the undercarriage jacks can be readily located to suit the individual wing and fuselage layout. With provision for inspection and reasonable maintenance, there should be little danger of rendering the retracting mechanism useless through burst piping or leaking connections. Furthermore, a higher efficiency and lower weight are generally possible, and, since standardised units such as pumps, control valves, jacks, etc., are used, the hydraulic system should prove more economical; especially is this the case where wing flaps are also coupled up to the same system and operated from a common pump unit.

I am not pretending, of course, that we have escaped the inevitable experimental snags which accompany the development of most new ideas during the

early stages of commercial exploitation. One danger that has to be carefully watched is the intrusion of foreign matter into the oil system, particularly during filling. Another vexatious problem that we had to face was the inability of ordinary flexible hose connections to stand up to the oil pressures developed. Our present practice is to use ordinary steel or copper piping coupled up to specially designed swivel joints where necessary, to take up the undercarriage movement instead of throwing it into the pipe lines.

The question of piping deserves careful attention in hydraulic systems for, obviously, frictional losses must be reduced to a minimum if the installation is to be an efficient one. Friction in the pipe line is: (1) Directly proportional to

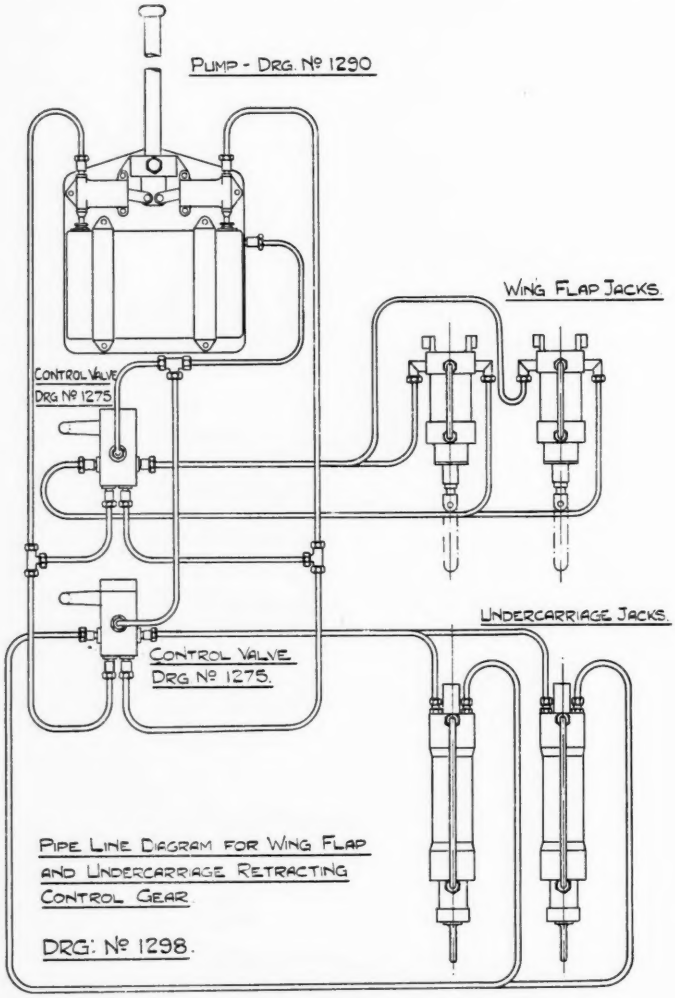
PUMP - DRG. Nº 1290
WING FLAP JACKS
CONTROL VALVE DRG Nº 1275
UNDERCARRIAGE JACKS
CONTROL VALVE DRG Nº 1275.
PIPE LINE DIAGRAM FOR WING FLAP AND UNDERCARRIAGE RETRACTING CONTROL GEAR
DRG: Nº 1298.

FIG. 33.
Installation diagram: Manual-hydraulic system.

the length of pipe, (2) inversely proportional to the pipe diameter, (3) approximately proportional to the square of the velocity, (4) independent of pressure in the lines, and (5) it increases with the roughness of the interior surface. It follows that the length of piping should be a minimum and the diameter as large as practicable, depending on the volume of fluid to be moved in a given time. To reduce surface friction to a minimum, the bores of all pipes should be made as smooth as possible and thoroughly cleaned at frequent intervals. Frictional losses due to pipe curvature mean that pipe runs should be as direct as possible and the radius of curvature should be large, since friction increases as the ratio R/D is reduced, where R is radius of curvature and D is the diameter of the pipe. Thus, for example, when R/D is unity, the friction loss is twenty times as great as when R/D is equal to 10.

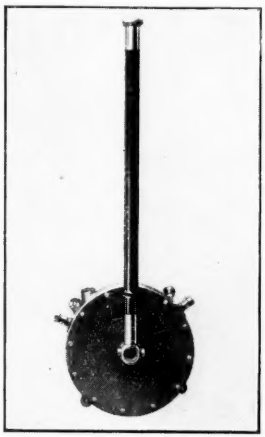

FIG. 34.
Hand-operated hydraulic pump.

1. *Manual Hydraulic Systems.*

Manually operated hydraulic systems usually consist of a pump unit with operating handle, a control valve for changing the direction of flow, and hydraulic jacks for movement of the undercarriage structure. Fig. 33 shows a typical installation diagram arranged to operate wing flaps as well as undercarriage jacks, a common pump unit feeding a separate control valve for each set of jacks. The pump itself is a two-cylinder unit enclosed in an electron body, which also serves as an oil tank or reservoir for the system. The pattern of pump illustrated in Fig. 34 is capable of developing a pressure of 1,200lb. sq. in., and at 250lb. sq. in., a delivery of one gallon per minute can be obtained.

The control valve, a section of which is shown in Fig. 35, might be described as the nerve centre of a hydraulic system. It comprises a rectangular electron body having two main vertical passage ways controlled by two balls in each passage. Each set of balls is operated through distance rods and springs by cams mounted on the spindle of the operating handle, the cams being set at 90° to each other. Reference to the figure shows that when the upper ball of each set is held on its seating, the lower ball is unseated and *vice-versa*. As illustrated in the right hand view (section " BB "), oil from the pump is fed in at the bottom of the control valve and is then by-passed through the right hand side

conduit to the jacks. (It should be noted that the oil pressure holds the bottom left hand ball firmly on its seat.) Oil flowing from the jacks passes through the left hand conduit and by the upper left hand ball to the outlet connection seen on the extreme left of section " BB," whence it returns to the reservoir.

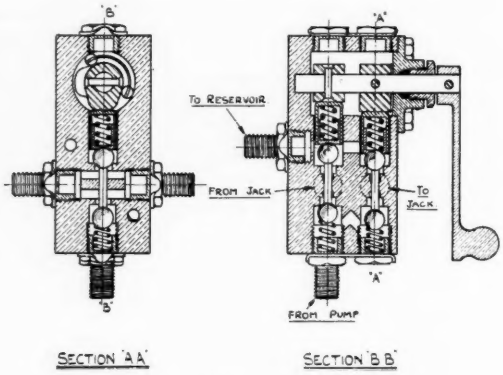

FIG. 35.
Control valve: Hydraulic system.

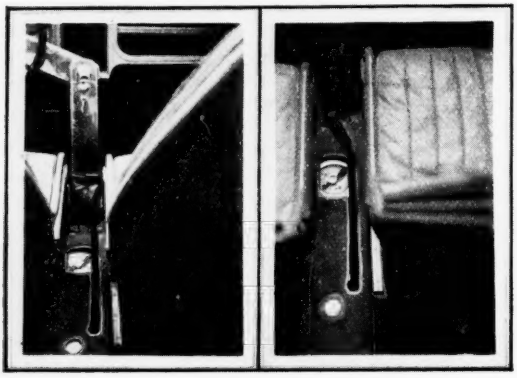

FIG. 36.
Hand pump and control cock installation, Heston " Phœnix."

Like all fluid systems depending on valves, these units are perfectly satisfactory, provided the system is kept clean and free from foreign matter. To this end, a generous sized filter is installed in an accessible place in the return line to the reservoir, so that frequent cleaning may be carried out to a definite maintenance schedule.

From the point of view of the aircraft layout it is a good plan to mount the pump and control valve in close proximity, and within comfortable operating position for the pilot during take-off and landing. A typical arrangement showing evidence of careful planning from the pilot's angle, is represented by the Heston " Phœnix " installation (Fig. 36). In this machine, the pump unit and control valve are mounted on the floor between the two front seats, easily

accessible from either seat, the control valve being operated by a two-way cock, similar, in fact, to the ordinary petrol cock.

On the ground, the pointer is kept fully home in the " down " position, with the pump handle registering a " solid " resistance to further movement. After taking off, the control cock is turned through 90° to the " up " position, and the pump operated until a solid resistance is again felt in the handle, indicating that the gear is up and fully home. Reversal of the cock to the " down " position enables the gear to fall about halfway by gravity, after which

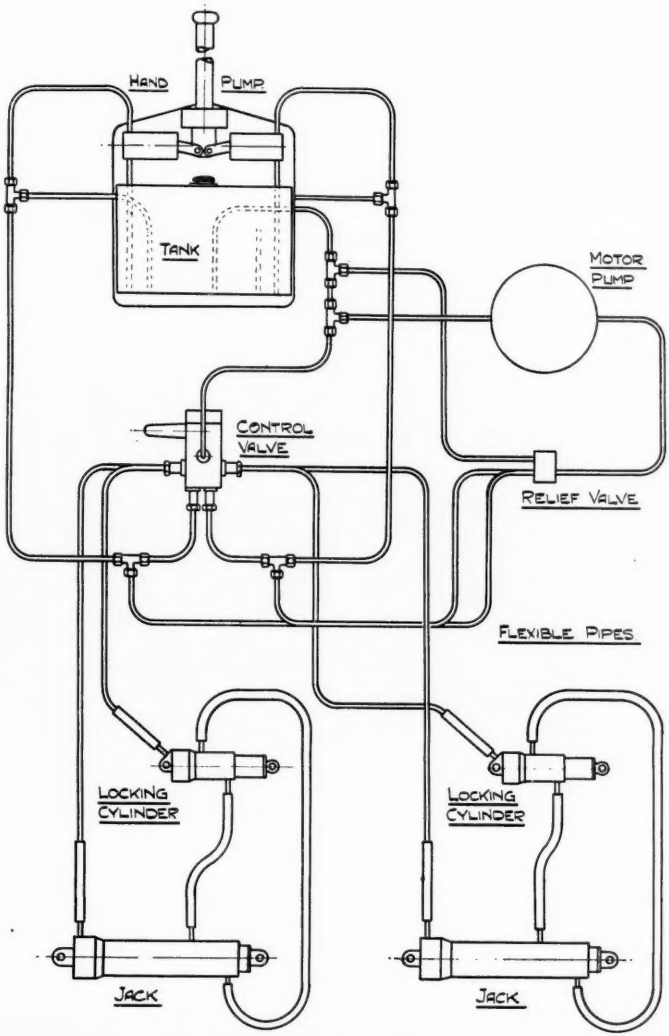

FIG. 37.

Installation diagram: Electro-hydraulic system.

the pump must be operated until the gear is fully extended. This will be indicated by the building up of fluid pressure in the system until the handle is once more " solid." The " Phœnix " undercarriage takes about 14 seconds to raise and 8 seconds to lower, the pump being handled in steady fashion without undue haste.

2. *Electro-Mechanical Systems.*

Power-driven retracting systems employing an electric motor with some form of mechanical coupling to the undercarriage structure are more in fashion in the United States than in this country at present. In my view, these systems are inclined to be heavy, since it is generally necessary to introduce a gear box with a large gear reduction and complicated shaft drives. On experimental machines, at any rate, such a scheme has not the flexibility of a hydraulic installation. The other alternative is to install individual motors at every power point, such as the undercarriage units, tail wheel, wing flaps, etc., which results in a multiplicity of power units throughout the machine.

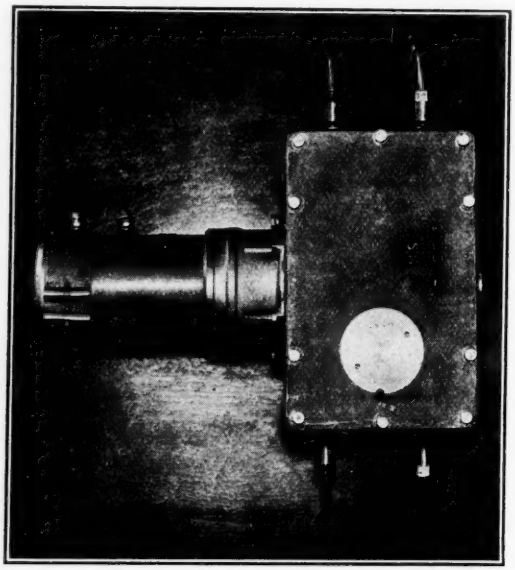

FIG. 38.
Electrically-driven hydraulic pump.

The Vultee transport, already described, is probably one of the best known exponents of an electrically-driven mechanical system, a single motor in the fuselage driving a transverse worm shaft coupled directly to worm sectors at the top of the cantilever shock struts. I believe that the weight of this scheme, undercarriage plus motor and gear system, amounts to about 7 per cent. of the gross weight of the aircraft. While this may be a little on the heavy side, there is no denying that the whole layout is very straightforward, and it is undoubtedly thoroughly reliable.

A further example of electric motor drive with mechanical coupling is installed on the Fairchild amphibian already illustrated in Fig. 12. To simplify

the control of all movable elements—undercarriage, tail wheel, wing tip floats and wing flaps—a master gear box is employed to obtain either manual or electric drive to any unit from one central power station. The electrical system is so arranged that movement of a selector lever not only throws the proper clutch to engage the desired unit, but also connects the corresponding travel limit switches into the driving motor circuit.

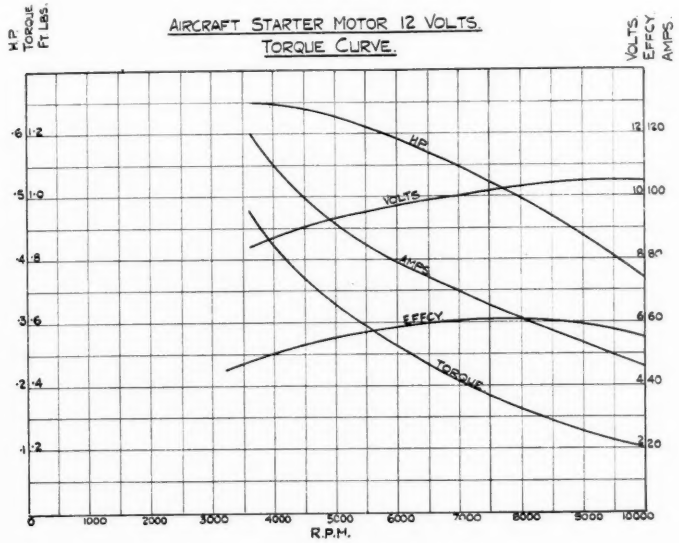

FIG. 39.

Electric aircraft starter motor, performance curves.

3. *Electro-Hydraulic Systems.*

One of the most successful power systems in use at present is obtained by means of an electric motor drive to a hydraulic pump. Fig. 37 shows an installation diagram with a power motor in the hydraulic circuit, while Fig. 38 is a view showing how the pump unit is coupled up to work off a standard B.T.H. electric engine starter. The motor is rated at ½ h.p. at 8,000 r.p.m., and operates from 12 volts with a consumption of 60 amps., driving a two-cylinder pump through a 40:1 worm reduction. The electron pump casing was originally used as the oil reservoir, but the high speed of the gears churned the oil to such an extent as to starve the pump and to produce an erratic operation, hence a separate reservoir is now incorporated. The whole unit is mounted to the aircraft structure on rubber insulation and although the complete installation is comparatively heavy, it has proved very reliable under heavy working conditions. Fig. 39 shows performance curves of the electric motor.

A more recent development of the scheme is a combined power and hand pump, with the motor mounted on the gear box and carrying a rocking shaft with hand lever. Two sets of twin cylinders are employed, one set driven by the motor and the other one for hand operation. The two systems are independent, so that a breakdown of any part will not affect the operation of the other system. The inlet and outlet pipes are common to both systems to avoid the extra weight and complication of duplicating the pipe lines. The system is provided with a

large reservoir having a capacity of two gallons, as the ram displacement of the undercarriage jacks is large.

4. *Engine-Driven Hydraulic Systems.*

Fig. 40 illustrates a simple gear type pump, designed for direct drive coupling from the aircraft engine. This pump will operate satisfactorily at

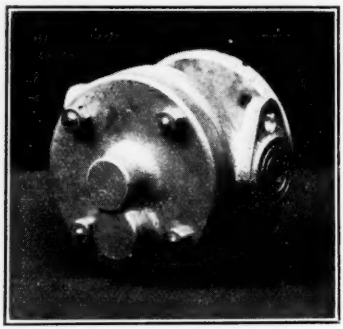

FIG. 40
Engine-driven hydraulic pump.

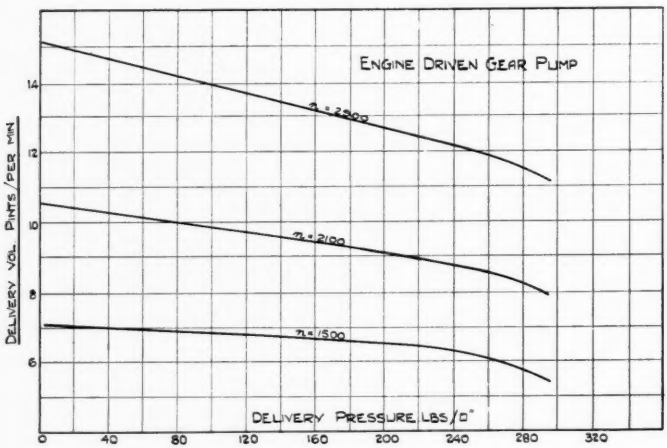

FIG. 41.
Engine-driven hydraulic pump, pressure and output curves.

speeds between 1,000 and 2,500 r.p.m., and is in continuous operation during flight, although its useful load period is only for some 60 seconds duration. Experiments conducted by our company indicate that a pump of this type cannot reach the efficiency of some other forms of power unit. Pressure and output curves are shown in Fig. 41.

5. *Pneumatic-Hydraulic Systems.*

In order that the undercarriage jacks, pump and reservoir shall be of low weight and, therefore, as small as possible, it is advisable to keep the working pressure in the oil system reasonably high. The pressures in most hydraulic systems vary between 250 and 700lb. sq. in., hence there is some difficulty in operating the undercarriage retraction directly by compressed air because it is not possible to tap directly from the present standard air bottles; a means for stepping up this pressure must be found.

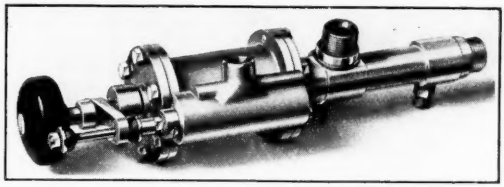

FIG. 42.
Pneumatically-driven hydraulic pump.

Fig. 42 shows a pneumatic motor which has been developed for this purpose, while Fig. 43 is a plot of oil pressure and output at three different air pressures and two different piston ratios. Air is passed into the large cylinder through oscillating valves, which reverse when the piston reaches the end of its travel. The main piston operates a smaller double-acting piston through a long connecting rod, and this smaller piston and cylinder unit supply oil under pressure. It follows that the oil pressure will depend on the ratio between the two piston diameters and the initial air pressure. Provision is made for auxiliary hand operation should the air supply fail and the hand knob for this is carried on an extension of the main piston connecting rod. From the tabulated weight data it will be noted that the weight of this type is very light.

WEIGHT OF PUMPS AND CONTROL VALVE.

Fig.	Description.	Weight. lbs.	ozs.
34	Hand-Operated Pump	5	5
38	Electro-Hydraulic Pump	16	0
42	Pneumatic-Hydraulic Pump	5	7
35	Control Valve	1	2

Emergency Lowering Mechanisms

To make reasonably sure that the undercarriage will return to the landing position, should the normal operating mechanism fail through a mechanical fault or through the crippling of the control system by enemy action, it may become necessary to provide some auxiliary means for lowering and locking the undercarriage in such cases of emergency. This emergency mechanism is additional to the power and manual stand-by gears normally fitted. In the system shown in Fig. 44, a jack somewhat longer than that required for retraction, houses a spring which is normally held compressed by a pin lock. In case of emergency the pin can be withdrawn and the spring will force the undercarriage down. This system is light in weight, since the undercarriage has a considerable gravity fall and the location of the spring provides a good mechanical advantage to hold the undercarriage home in the down position.

Fig. 45 shows another scheme with the same end in view. In this arrangement the central member of the hydraulic jack is actually a reservoir which can be charged with air under considerable pressure. Should the lowering mechanism

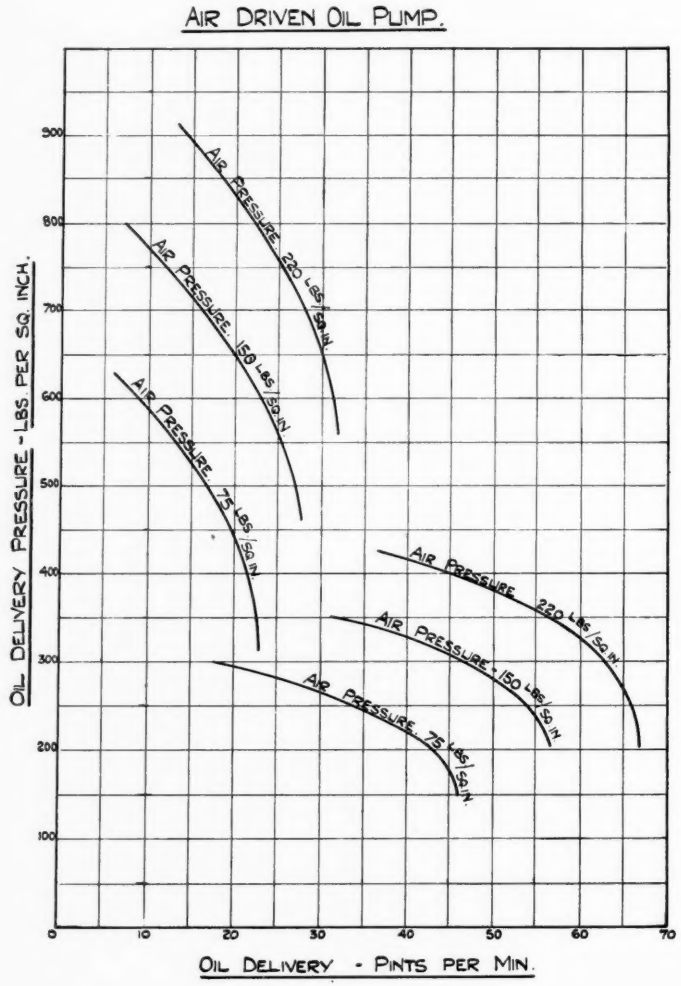

FIG. 43.

Pneumatically-driven hydraulic pump, pressure and output curves.

fail, the operator can manipulate a control which simultaneously blanks off the hydraulic system and places the reservoir in direct communication with the jack, thereby insuring a speedy and positive return of the undercarriage to the landing position. Here, again, a feature of this auxiliary system of lowering is a negligible increase in weight.

Safety Locks

The security of a retractable undercarriage depends in very large measure on its locking gear. Even in such cases where the folding structure is designed to pass over dead centre, so that landing loads tend to prevent structural collapse, auxiliary locks are most desirable as a further safeguard and, shall we say, to inspire confidence in the flying personnel. Furthermore, locks for holding the undercarriage in the retracted position sometimes result in a lighter structure, at the same time relieving the retracting mechanism from inertia loads in flight.

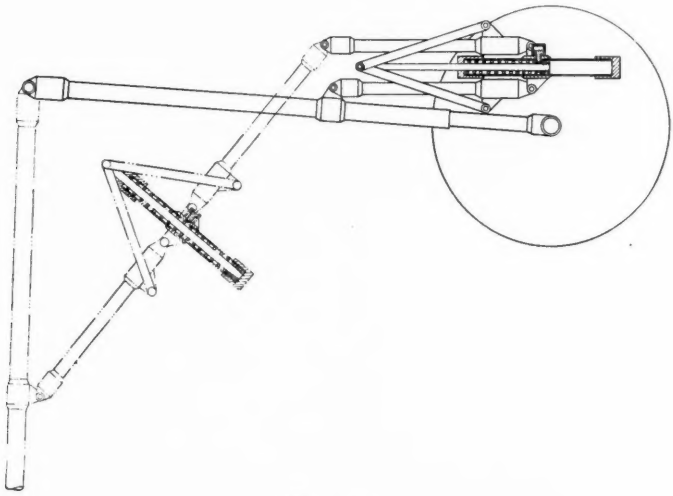

FIG. 44.
Emergency lowering mechanism, spring type.

A typical lock is shown in Fig. 46. Normally the lock is held in engagement by a tension spring, such that when the undercarriage pin moves to its extreme position, the latch folds back against the spring load and then snaps into position. In this arrangement the lock is released hydraulically by coupling the " up " lock to that side of the system which is under pressure when the undercarriage is being lowered and, conversely, the " down " lock to the side under pressure when the undercarriage is being raised. The pressure, of course, moves the piston forward, thereby throwing the latch out of engagement with the pin.

Position Indicators

At the present stage of development, warning indicators or signal devices for showing the position of the undercarriage are conspicuous by their lack of conformity to any recognised requirements. Perhaps in the discussion some of the aircraft designers will advance their views on this debatable topic. My own experience, so far, leads me to think that two different forms of warning should be given to the pilot; a visual signal on the instrument dashboard, either mechanically or electrically-operated, and an audible device such as a buzzer in close proximity to the pilot's head, the buzzer being arranged to sound at about one-third opening of the engine throttle when the undercarriage is up or not yet locked for landing.

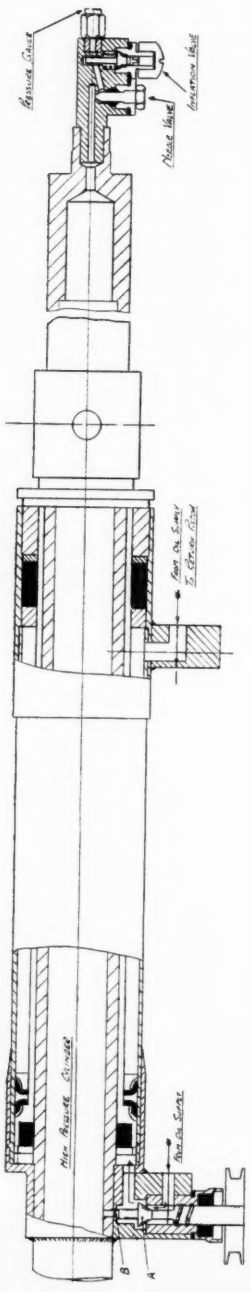

FIG. 45.
Emergency lowering mechanism, pneumatic type.

Mechanically-operated indicators of the type comprising a signal arm or pointer moving over a scale are generally operated through a flexible control of the Bowden or Simmonds-Corsey type connected to some moving part of the undercarriage structure. An advantage of the mechanical installation is that the operator can see at a glance the approximate position of the undercarriage at any time, which undoubtedly inspires confidence, especially if the instrument is mounted on the dash close to the air speed indicator. It is possible, however, that an electrical indicator is still necessary, if for no other reason than the possibility of failure in the mechanical system.

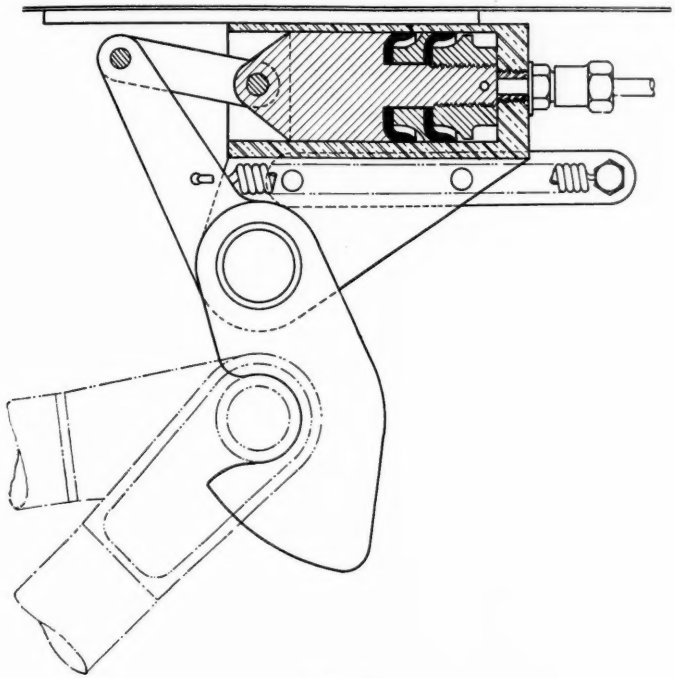

FIG. 46.
Undercarriage safety lock.

A typical electrical indicator system for retractable undercarriage and tail wheel is shown in Fig. 47. A desirable feature is that the actuating plungers should be incorporated in the latch locks in such a manner that the indicators can only be operated when the pins are right home. Since the all-important indicator is the " down " one, this should have duplicate wiring with two bulbs enclosed in separate chambers on the dashboard. Failure of either circuit is at once apparent, so that it can receive immediate attention. The system illustrated employs a red lamp to show all the time the undercarriage is " up," changing to amber during the lowering operation, and finally to green when locked in the " down " position.

Tail Wheels

Of more recent date than the retractable undercarriage, its offspring, the retractable tail wheel has still to prove its worth—to earn its board and lodging,

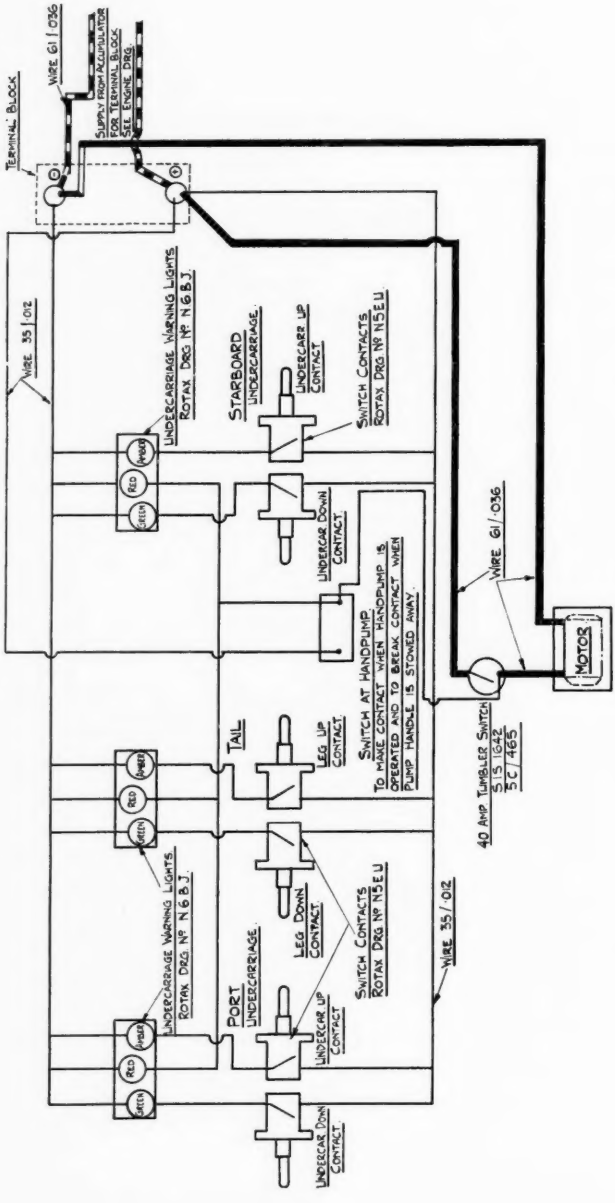

FIG. 47.
Electrical indicator system.

so to speak. The aerodynamic merit is difficult to assess with any precision, since reliable full-scale drag figures are conspicuous by their absence. Moreover, it is my current experience that there is a decided divergence of opinion among aircraft designers themselves regarding the value of tail wheel retraction, hence I should like to submit a plea for some *large-scale* research on this subject. Neglecting altogether the engineering economics of the problem, I fancy that the case for tail wheel retraction will be decided on quite other grounds—and for a reason very common in the automobile industry; what the automobile designer is pleased to call " style " or " sales appeal." I think you will agree that for appearance sake, it looks somewhat incongruous to see an exposed tail wheel in flight, on an otherwise very clean aeroplane with fully retracting undercarriage. My own view, then—probably a biased one, no doubt—is that all future high speed aircraft with retractable undercarriages will feature a retractable tail wheel as well.

Actually, when one comes to study the situation, the problem is generally capable of a neat solution with very little increase of weight because we are playing hide and seek with a single cantilever strut, which readily lends itself to simple fore and aft retraction into the fuselage. The real issue, then, is whether the additional cost and complication are justified by the saving in drag; and in the case of commercial aircraft, at any rate, by the gain in " sales appeal " resulting from the general air of cleanness. I do not think that this angle of sales psychology has been sufficiently appreciated by our commercial people in the past. Perhaps the influence of military requirements has tended to obscure our commercial vision. On the other side of the Atlantic, however, they seem to have developed the art (or is it a science?) into a subtle sixth sense for diagnosing the public pulse in these matters.

The two schemes so far developed by my Company are essentially similar in that they both consist of a fully castoring tail wheel carried in a fork on the end of a single shock absorber unit mounted on trunnions to the fuselage, and free to swing in a fore and aft plane by hydraulic action. The tail wheel unit comprises a shock absorber strut, using steel springs for landing and taxi-ing loads. A feature is the self-centring device enclosed within the strut itself, and which holds the wheel in a true fore and aft position directly the load is released. During flight the wheel remains in this position and cannot be disturbed by air and inertia forces. The self-centring does not affect the castoring action of the wheel, which may be rotated through any number of turns for manœuvring on the ground.

It was originally intended that coned friction dampers should provide a complete check to instability of the wheel, since the dampers were controlled by the shock absorber and the degree of damping varied in direct proportion to the applied load. More recently, however, it has been found advisable in some cases to add an adjustable brake in the form of a friction band to the outside of the shock absorber tube, as an extra safeguard against wheel shimmy. Because the incorporation of these brake bands tends to nullify the self-centring action of the wheel, especial precautions are now taken to waist the shock absorber tube over a short distance, so that the brake band is non-effective when the shock strut is fully extended with zero load on the wheel.

Fig. 48 shows a method in which the upper end of a hydraulic jack is pinned to the fin post and the lower end to a crank on the tail wheel shock strut at the trunnion bracket, such that compression of the ram rotates the shock strut and tail wheel into a horizontal position. The upper end of the shock strut is held in a self-acting lock when the tail wheel is in the landing position. Oil pressure for retraction unlocks this catch before the retracting jack starts operating.

Figs. 49 and 50 show a more compact retracting unit. Two hydraulic cylinder and piston units are formed on the shock absorbing member, one at the

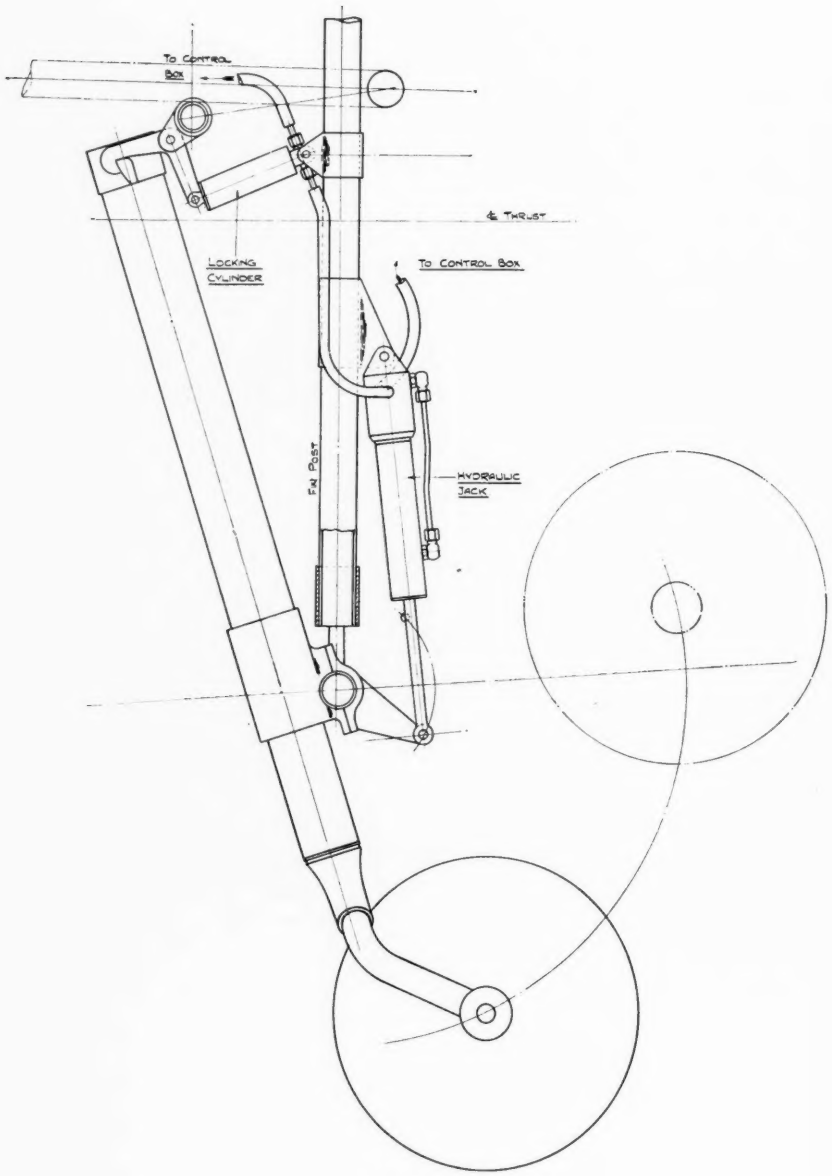

FIG. 48.
Retractable tail wheel.

top end, and the other on one side above the swivel trunnions. The piston rod extending from the side cylinder carries a link hinged to a bracket or offset lever, such that a moment may be produced about the trunnion axis. As the piston rod is extended, the tail wheel unit is rotated into a horizontal position. Normally the shock strut is retained in its upright position by a spring loaded plunger lock at the top end. This plunger is forced home and withdrawn by oil pressure, suitable by-passes being provided to ensure that the lock operates before the main retracting jack commences to function. A good feature in view of previous remarks on piping troubles is that there are no flexing pipes in this assembly,

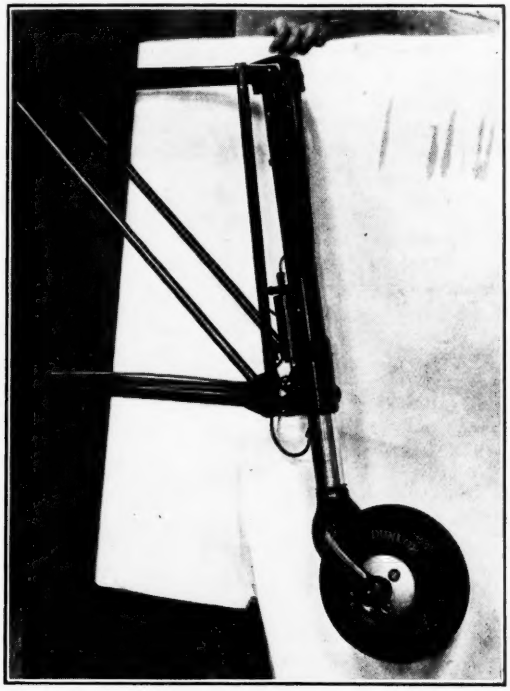

FIG. 49.
Retractable tail wheel.

the fluid being taken through ducts provided with suitable glands. The structural price paid for retraction of a tail wheel in this manner is approximately 3lbs. for a machine of 6,000lb. gross weight.

Conclusion

Through the impetus of world competition, rapid strides have been made during the past year or two in the speeds of commercial aircraft, and it is my belief that the adoption of the retractable undercarriage has played a decisive part in this advance. I am encouraged in this belief by the significant fact that what was once a novelty has now become an accepted operating feature of the world's leading airways, despite a great deal of prophetic cold water in the past. Sup-

pression of the undercarriage " parasite " by retraction in flight has now passed into the realm of mechanical feasibility to such an extent, indeed, that it is no exaggeration to say that the great majority of high speed aircraft now under construction, have been initially projected with a retractable undercarriage as a matter of course. From now on, any aeronautical engineer wishing to keep abreast of his art, will accept them as a part of his normal design technique. I am led to hope, therefore, that some of the schemes discussed may prove helpful to other workers in this field.

While appreciable gains in performance have been realised from this source, I do not wish to suggest before such a critical audience as this, that in engineering design we can ever expect something for nothing when weighing up our final balance sheet. Day dreaming with the gulls on London Bridge may be a pleasant interlude in the workaday routine, but the engineer has still to face

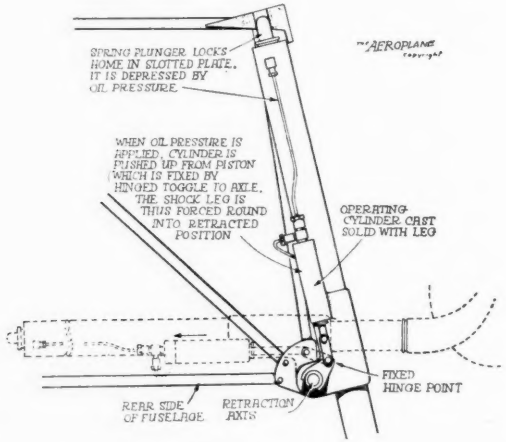
SPRING PLUNGER LOCKS HOME IN SLOTTED PLATE. IT IS DEPRESSED BY OIL PRESSURE
WHEN OIL PRESSURE IS APPLIED, CYLINDER IS PUSHED UP FROM PISTON WHICH IS FIXED BY HINGED TOGGLE TO AXLE. THE SHOCK LEG IS THUS FORCED ROUND INTO RETRACTED POSITION
OPERATING CYLINDER CAST SOLID WITH LEG
FIXED HINGE POINT
REAR SIDE OF FUSELAGE
RETRACTION ARMS

FIG. 50.

Tail wheel retraction unit.

the difficult task of assessing added weight and extra cost against the alluring wiles of the performance chart. It has been stated elsewhere in the paper that undercarriage retraction cannot be applied wholesale to any type of aircraft, irrespective of size or duty, and I have in mind some definite cases where its installation would be a reckless extravagance. All the same, I do suggest that the history of aeronautical engineering repeatedly teaches us that if we need something badly enough aerodynamically, the ingenuity of the mechanical engineer can be relied upon to overcome the mechanical snags and to produce a satisfactory solution once the problem is defined and placed before him.

Too often in the past, we in this country have been prone, I think, to look upon the problems of parasite drag reduction as an idealistic dream, rather than an economic first principle, to be weighed in terms of the highest possible operating speed for a given power expenditure. We have allowed the maintenance engineer to trespass far into the domain of the aeronautical engineer, until the stress of competition along the world's airways has made our past conception of " comfort without speed " an untenable one, and I venture to think that the retractable undercarriage has forced the pace to a measurable extent.

In conclusion, I have to thank the following firms and individuals who have generously supplied me with illustrations and data regarding many of the schemes

described in the text:—" The Aeroplane," " Flight," " Aviation," " Aero Digest," Messrs. Aircraft Components, Ltd., Airplane Development Corp. (Vultee), Douglas Aircraft Co., Inc., Gloster Aircraft Co., Ltd., Hawker Aircraft, Ltd., Heston Aircraft Co., Ltd., Engineering Division U.S. Air Corps, Mr. A. V. Verville, and Flt.-Lieut. W. E. P. Johnson.

Finally, my grateful thanks are especially due to my friend, Mr. Stanley H. Evans, for his valuable collaboration and constructive criticisms in the preparation of this paper.

Discussion

Major D. H. Kennedy (who occupied the chair at this stage at the request of the President, who had to leave): He complimented Mr. Dowty upon having given a most excellent résumé of the problem of retractable undercarriages. The reference to the seagull, in the opening sentence of the paper, he said, emphasised that from the beginning of heavier-than-air flight they had had before them that example to remind them that attention to this subject would yield valuable results; the fact that heavier-than-air flight had been practised for about one-third of a century, and that they were only now bringing this matter of retractable undercarriages into the prominence it had long deserved, was sufficient indication that the problem had not been without its difficulties.

Mr. A. Hessell Tiltman (*Fellow*): He would like to comment on the reference made in the paper to the teething troubles experienced in the early development of the retractable undercarriage. He recalled that his Company also had experienced minor troubles. Perhaps the greatest of the troubles was experienced in connection with the flexible pipes in the hydraulic system. On one occasion it was found that a mechanic had partially pierced one of these flexible couplings by means of a screwdriver, and the trouble was not apparent until someone had made a bad landing. On another occasion the armouring of the flexible hose itself had pierced the tube. But it was interesting to note also that quite a number of mishaps were due to pilots simply forgetting to put the undercarriages down before landing. In America, he understood, there had been a lot of trouble due to this cause, and the Americans had tried all sorts of arrangements to remind pilots that before landing they must put the undercarriages down. One firm had arranged a small electric motor attached to the base of the joystick; the spindle was eccentrically mounted, and when the undercarriage was up and the throttle closed it wobbled the joystick, so that it was very difficult for a pilot to forget.

With regard to the pooling of patents, Mr. Tiltman said that when in America this year he had asked a number of designers whether the pooling scheme was working well, and he was told by everyone he had asked that it was a great boon to be able to attend a meeting of a committee of arbitration and to thrash matters out in comfort. From the number of diagrams Mr. Dowty had exhibited it must be apparent that the number of patents concerning retractive undercarriages was so large as to render the whole patent position very complex. He wondered whether the Royal Aeronautical Society could appoint a committee to investigate the difficulties and possibilities of an Arbitration Committee being appointed to pool the resources of patents in this country; all concerned would feel very much happier if there were in existence such an arbitration committee.

As to the future of retractive undercarriages, it was his personal opinion that finally it would be an electrical job. The multiplication of different systems throughout an aircraft was becoming something of a nightmare, and he felt it would help greatly to ease that difficulty if all retractable undercarriage systems were electrical. Aircraft must be fitted with an electrical system for wireless and for landing lights in any case, and the avoidance of hydraulic and compressed air systems might be a good thing.

Mr. O. E. Simmonds (*Fellow*): The paper reminded him that with the Royal Aeronautical Society was incorporated the Institution of Aeronautical Engineers. Possibly it had been thought that some of the papers presented to the Society were a little too scientific and academic and that the practical side had not received sufficient attention in the lecture programmes. He believed that one of the difficulties encountered in correcting the balance was to find suitable papers, and above all, suitable men to present those papers. The meeting ought to thank and congratulate the Lecture Sub-Committee on having secured a paper on retractable undercarriages from Mr. Dowty; and Mr. Dowty himself, most certainly, must be congratulated on his success in presenting so complete a picture of the subject, both historically and otherwise, a task which must have involved a great deal of trouble. Mr. Dowty appealed to all technicians not only because he had shown himself to be a good designer, but also because he had proved himself a capable business man, and he was to be congratulated on his technical and commercial success. Mr. Dowty and himself had marched along parallel roads, for they had both set out to try to prevent a state of affairs arising, as they felt it would arise in the course of about six years, in which every designer would be admitted to a mental home. There was not the slightest doubt that the complications of modern aircraft were increasing at such a rate that it was obviously necessary for specialists to enter the industry; and he did not think he was doing Mr. Dowty an injustice in saying that the man who had brought this conception to a fine art was Mons. Messier, who, most unfortunately, was killed recently.

An important point to be borne in mind by all designers in regard to the specialist companies was that they did form clearing houses for particular aspects of the art; and Mr. Dowty had shown how valuable such a clearing house could be, not only in respect of knowledge obtained in this country but also in respect of that gained abroad. Mr. Dowty supplied undercarriages and tail wheels to almost every country in the world; he was virtually a consultant co-operating with designers throughout the world, and the knowledge of what was being done in the various countries must clearly redound to the benefit of the British aircraft industry. Another consideration was that many of our best aircraft to-day were being constructed under licence in foreign countries. A great danger in such circumstances was that the foreign-constructed aircraft might not be quite up to the standard of the British product, and for that reason there might be a reaction in the neutral markets against British aircraft. Therefore, it was essential that the construction of the more complicated parts of the modern aeroplane should be in the hands of those who understood those parts, and it was wise that nearly all the foreign purchasers of licences—usually they were Governments—turned to the British patent component manufacturing concerns to supply the actual components for the foreign-made aircraft.

Mr. Dowty had given an immense amount of information, and as a result of it every designer would certainly be in a better position than he had been previously to design a retractable undercarriage or tail wheel. Not only had Mr. Dowty dealt faithfully with the meeting, but he had also shown his confidence in himself. He had been through the mill in finding out what the Americans called the " bugs " in the various designs. Therefore, when one turned to such a man and to such a Company as his to solve one's problems one knew that in what he would provide he would have solved many of the major difficulties. Thus one was safeguarded.

Mr. G. Cornwall (*Associate Fellow*): The paper would be a standard work on undercarriage design for at least a year or two. In order to assess relative values, Mr. Cornwall asked what extra performance they were getting in an aeroplane, by reason of the fitting of a retractable undercarriage, in return for the £'s sterling and the lbs. avoirdupois added thereby to the cost and weight of the aeroplane. In this connection he asked whether there was in existence

a machine which at successive stages of its history had been fitted with a retractable undercarriage and a decently faired non-retractable undercarriage, preferably of the cantilever kind, so that a comparison could be made of the performance of the machine under those two conditions.

Major F. M. GREEN (*Fellow*): The usefulness of the paper would be still further enhanced if Mr. Dowty could give some idea of the increase of weight, say, as a percentage of the total weight of an aeroplane, due to the fitting of the retracting mechanism. With the aid of such information one could probably more easily estimate the net advantages or disadvantages arising from the use of a retractive undercarriage. It was fairly clear that in the case of high speed machines the saving in petrol consumption would easily be sufficient to pay for the increased weight of the undercarriage; but it would be valuable to have an idea of the actual weights of the retractable undercarriages.

Mr. M. LANGLEY (*Member*): He welcomed Mr. Dowty's practical paper as one which would be of the greatest use in the drawing office in solving the mechanical difficulties which arose. He asked if it were mechanically possible to combine the mechanism of the shock absorber strut with the mechanism of the retraction system; and if so, whether Mr. Dowty considered it worth while.

With regard to weight, one knew that the old tripod or multi-pod type of exposed landing gear weighed about $4\frac{1}{2}$ per cent. of the gross weight of the aeroplane, and it seemed possible to design a very clean cantilever undercarriage for a light aeroplane, which would weigh about 5 per cent. of the gross weight of the machine. The only weight that he could find mentioned in the paper for a retractable undercarriage was that of 7 per cent., in the case of the Vultee. But possibly the weight in that case was more than 7 per cent., because the figure related only to the undercarriage itself and there was no reference to the increase of weight in the wing structure necessitated by the fitting of the retraction gear—the fitting of that gear had an effect on the wing spars and covering weight. An increase of 2 per cent. in gross weight by reason of the fitting of a retractable undercarriage might be worth while in a large aeroplane, even though that increase was equivalent to the weight of one or two passengers. But he doubted that it was worth while in a small two-seater machine, particularly in view of the difficulties involved in the maintenance of the mechanism. He could imagine an extension to the ground engineer's certificate being provided specifically to deal with hydraulic retraction gears and their attendant troubles.

One other aspect of undercarriage design which was perhaps implicit in the paper, but should be mentioned specifically, was that of the types of aerodromes from which the machines operated. Machines such as the Vultee, which were used largely for inland routes in America—as distinct from the Pan-American Line machines, which were operating on routes such as the Empire routes—operated from aerodromes such as did not exist in this country, for they landed on and took off from concrete strips, and the machines were designed for such conditions. The travel in the compression leg could be, and was usually, much less and this simplified the design of the retraction gear. On the other hand, in this country one designed undercarriages to meet the conditions which existed at Martlesham and Farnborough!

Mr. E. C. GORDON ENGLAND (*Fellow*): A horribly commercial thought had occurred to him. He recalled that at the last meeting of the Society the lecturer, who had dealt with scientific investigations into the problem of the abatement of noise in aircraft, had yet related everything to commercial results and had felt that it was only worth while proceeding with such an investigation so long as he was likely to get results which would bring increased revenue to the aircraft operator. Mr. Dowty, on the other hand, had given an excellent paper, but had ignored commercial considerations entirely and so on this point his listeners were left in the air. He had assumed that the case for the retractable undercarriage was made, but one would be glad to hear some facts which, from

the purely commercial point of view, would justify the use of the retractable undercarriage. One had to consider the various components, the increased cost and the complexity of the structure and its control, and on the other hand there was obviously a reduction of head resistance as the result of the retraction of the undercarriage, and so on. It should be possible for Mr. Dowty to draw up, say, a chart which would show the horribly commercially-minded men who had to control aircraft firms that they had not a leg to stand on in opposing the adoption of the device in all their designs. Possibly it could be shown that in regard to very small low-speed, low-power aircraft the game was not worth the candle; but there must be a point at which, from commercial considerations alone, an indisputable case could be made out. One assumed that Mr. Dowty himself was satisfied on the matter; but he would render a service to others if he could add a diagram or chart to show the position.

It was stated in the paper that possibly there was no case for the retractable undercarriage, mechanically operated, on the small aeroplane. In Mr. Gordon England's experience, however, the view held in America was distinctly opposed to that, the point being—and probably it was a good one—that pilots were liable to forget to put down their undercarriages some time before landing. If the gear were manually operated it might take too long to operate, and that it was better that they should have some mechanical means by which to recover themselves rapidly before an accident could occur.

On the Beechcraft machines there was very rapid mechanical retraction, which was extraordinarily valuable at the take-off. Having flown a Beechcraft, Mr. Gordon England testified to the extreme value of the almost instantaneous retraction, effected by means of pneumatic controls. The moment the machine had left the ground it was extraordinarily free and gathered speed in a phenomenal manner. It appeared to be the view fairly generally held in America that there was a great deal to be said for mechanical retraction, even for the smallest aircraft; and he asked Mr. Dowty to say whether or not there was faulty reasoning in that argument.

Mr. W. O. Manning (*Fellow*): Commenting on Mr. Gordon England's reference to the value of folding the chassis immediately a machine had left the ground, he suggested that that was a rather dangerous practice, because in the event of a forced landing one would be very much better off if the chassis were not folded. His view was that, in the interests of safety, the chassis should not be folded until the machine had reached such a height that the chassis could be unfolded again, in the event of engine failure, before the machine reached the ground. That height would depend upon the design of the chassis.

He believed that the paper contained all the information extant with regard to retractable chassis, and that information was given in an extremely convenient form. In regard to details, however, Mr. Manning drew attention to the fact that in certain designs worm gears, screws and nuts and other contrivances of that sort were used to fold the chassis. It would appear that on certain aerodromes such appliances might become covered with sand, mud, etc., so that they were not likely to work very well; at least, under those circumstances considerable excess power would be required to fold or unfold the chassis. One supposed that there were methods of protection against such trouble, but in certain designs the solution of the problem would not appear to be too easy.

Referring particularly to the Douglas chassis, he said that in the drawing there appeared to be no method provided for taking the brake torque, though he felt quite sure that the Douglas machine was fitted with brakes.

Finally, Mr. Manning joined in the request for further information concerning weights of retractable undercarriages, in view of the vital importance of that consideration. Most designers would be able to make their own estimates of the increased speed of an aircraft resulting from the retraction of the under-

carriage; but that advantage had to be balanced against the extra weight to be carried, and the extra cost.

Mr. S. H. Evans (Heston Aircraft Co., Ltd., *Member and Associate Fellow*): Commenting on the lecturer's opening remarks, he said he was delighted to hear that Mr. Dowty made frequent excursions to London Bridge for the purpose of dreaming his quiet half-hours away with the gulls. Knowing and respecting his extraordinary mechanical ingenuity, over a period of many penurious years in the industry together, he felt he could now ask him to put up a retracting float scheme with every confidence of a neat solution! Commenting further on Mr. Dowty's reference to the shell "pterodactyl" as a parasitic nightmare, he said that was perfectly true; but it could not be denied that Nature was cunning enough even at that early stage to start with the right idea, for an inspection of the first figure would clearly show the birth of the cantilever wing and undercarriage. He rather thought they were now getting away from some of the past "birdcagery" and taking a look at the bird inside.

The subject matter of the paper, containing as it did so many ingenious mechanisms, many of them from the fertile mind of the lecturer himself, came at a very opportune time for aircraft designers in this country, since it looked as if most designers were exploring the enlarged technique involved. He felt that the work of Mr. Dowty's firm had been an invaluable asset to many of them, and certainly in the case of his own firm, he would like to acknowledge the able assistance and expert advice so freely given during the experimental development of their own machine. Experimental work of this nature inevitably brought snags to fight out and it was a comforting thought to know that Mr. Dowty's long and unique experience with undercarriage problems was ready to hand.

Perhaps the most contentious part of the paper, as it affected the aircraft designer rather than the undercarriage specialist, was the section on "Emergency Lowering Mechanisms," and he was disappointed that the lecturer's views had not drawn the fire of other designers, many of whom were present that evening. The point at issue was whether the ingenious emergency mechanisms described in the paper as Figs. 44 and 45 were really necessary at all. For his own part he could not help feeling that they ought to be more honest with themselves and label them as "funk mechanisms," the result maybe of a little "wind up" on the part of a few unfortunate pilots and designers with a limited experience of the new technique. The British lion was indeed a very docile creature to take this kind of "gadgetry" lying down, and if we went on tying his legs in this manner, he (the lion) might never get up at all. The speaker was genuinely concerned because it meant that they would lag behind the Americans again. Several speakers had already referred to the problems of extra cost, weight and complication on the debit side of retraction systems, and yet they evidently intended to accept the mandatory requirement of a triplicated operating mechanism. British designers were asked to load their machines with a power-operated gear, then a manually-operated stand-by gear in case of power failure, and on top of that very reasonable requirement, an *emergency lowering mechanism* (so called!) just in case the other two failed, which he ventured to think was altogether too silly and thoroughly illogical, in that excessive complication would defeat the end in view by confusing a pilot in a crisis; added to which one had a further maintenance problem in one's hands. He hoped, however, that this would be a passing phase because in the case of service aircraft, at any rate, pilots should be trained in the routine of undercarriage operation and even be prepared to take an "abdominal landing" now and again.

He had had the good fortune to see the Douglas "DC-1" (the well-known transport mentioned in the paper) take it on the chest a couple of times and he much admired the courageous attitude of the Douglas engineers and test pilot. Instead of adding another gadget, they diagnosed the trouble and licked the snags in the prototype, the result being that the Douglas undercarriage was

far and away the lightest retractable gear that had come within his knowledge. Furthermore, he could not recall one single American aeroplane, whether Douglas, Boeing, Vultee, Lockheed, Curtiss, etc., which carried around such a third funk mechanism and he thought it would be admitted that the Americans had had a much longer experience with retractable gears, both in military and commercial operation, than they in this country.

It was also disappointing that the question of indicators had not been raised by other designers, because he believed that many of them were not quite happy on that question and he would be glad of some definite expressions of opinion from designers with experience of retractable gears. At the moment it looked as if they might have foisted on them a mechanical indicator, then an electrical red-amber-green lighting system, plus a buzzer coupled up to the engine throttle in some manner, although the value of the throttle connection was lost in the case of sudden engine failure when badly needed. He, personally, was very much in favour of the mechanical signal arm on the dash, since he agreed with the lecturer that it did inspire confidence in the operating personnel. He was also in favour of the red and green lamp scheme actuated by the undercarriage locks, but at present he was in two minds regarding the value of any kind of audible device, as this was likely to be a passing phase only necessary during the initial period of transition from fixed to retractable undercarriage operation.

Finally, Mr. Evans said how glad he was to second Mr. Simmonds' remarks wherein he paid tribute not only to the lecturer's practical engineering vision, but also to his sound commercial acumen in exploiting a distinct avenue of his own within the industry. He had had the pleasure of knowing Mr. Dowty for a good many years, but he still had the greatest difficulty trying to keep up with his natural fecundity of mechanical invention. Ever since he first met him, he had kept up a steady stream of one idea after another, beginning at a very tender age by inventing a simple device to straighten bent nails and return them to circulation. More impressive than the invention, however, was Mr. Dowty's astonishing ability in selling the idea outright for £5—and that impressed him very much indeed as early evidence of Mr. Dowty's commercial sense. He ventured to think that the Society were indeed fortunate in cajoling him away from his meditations with the gulls and in getting him to place some of these ideas on record. Perhaps he might be forgiven for mentioning that he had had something to do with that, in that he had taken the liberty of suggesting the lecturer's name and subject to the Council of the Society, and he would take this opportunity of thanking the Council for adopting that suggestion.

Mr. G. Lyon (*Associate Fellow*): Although he had never designed a retractable undercarriage, he had been much impressed by the numerous pictures he had seen, in the aeronautical and even the daily papers during the last year or two, of aircraft which had landed with their undercarriages in the retracted position. There had been references to several other such incidents in the papers, and he believed the position was even more serious than it appeared from such references. Therefore, he asked if Mr. Dowty had been able to make any analysis of the causes of these accidents, and, if so, at what conclusions he had arrived. Mr. Lyon found it difficult to believe that pilots in general were so forgetful as would appear from Mr. Tiltman's remarks.

Mr. A. W. Clegg (*Associate Fellow*): The adoption of retractable and cantilever undercarriages had introduced new factors in the design of the shock absorbing member. In the older types of undercarriage the strut had only to deal with actual shock absorption; but in the newer types, torsional and bending loads due to brake operation, etc., had to be considered.

As regards the proposed Air Ministry regulations, although many safeguards were suggested, an analysis of the causes of failure of retractable undercarriages up to the present indicated that the imposition of such safeguards was justified.

The CHAIRMAN (Major D. H. Kennedy): He recalled that some years ago, when he had served as chairman of an editorial committee dealing with an aeronautical glossary, he had been brought very closely into contact with the problem of selecting words for use in the aeronautical industry. Although, throughout Mr. Dowty's paper and the discussion upon it, the word "retractable" had been used, he had been told that the word that should be used was "retractile." The United States Air Service used the word "retractile." He asked for Mr. Dowty's views on the subject.

A very important matter which had been raised in the paper and commented on in the discussion was that of the pooling of patents. Major Kennedy was strongly of opinion that the present chaotic position in regard to our patent laws and patents generally had a tremendously retrograde effect on the development of the industry, and he would certainly welcome the suggested pooling if it could be achieved. Mr. Dowty's attitude on the subject had betrayed his very generous mind. The solving of that difficulty would also help them to deal with the subject raised by Mr. Tiltman, *i.e.*, the amalgamating of all the Christmas tree gadgets which surrounded the present-day engine.

Mr. H. D. BOULTBEE (*Associate Fellow*) (*contributed*): With reference to Mr. Dowty's remarks on the early retractable undercarriages, he may be interested to note that a patent was granted to the writer in 1909 for one. This shows a one-wheeled undercarriage which he intended to use on a machine which he was then constructing. He was following the ideas of Messrs. Esnault Pelterie and Howard Wright that one central wheel would be satisfactory and also, of course, found it considerably easier to find room in the small fuselage for one wheel. It is obvious that until low wings became the fashion that the idea generally could not make progress.

He had naturally given a great deal of time to the design of retractable undercarriages and came to the conclusion some years ago that the gain in performance was not worth the additional complication involved. He believed that this is supported by recent full-scale tests in the U.S.A. He had recent experience of such design work and considered that a carefully faired cantilever shock absorber is to be preferred. If one considers the electric motors or pumps, slides, locking devices, electrical warning signals, covers to fair gaps, etc., not to mention the problems of maintenance, he could not see how a practical engineer could fail to choose which to adopt when the gain is something of the order of 6 m.p.h. at 200 m.p.h. All the same, he admired very much Mr. Dowty's numerous solutions of the problem and feels that undercarriage design will progress due to some of his ingenious mechanisms.

REPLY TO DISCUSSION

Replying to Mr. Tiltman's reference to electrical operation, he had been working recently on the idea that pneumatic operation for all auxiliary controls was possibly the most promising solution of the problem combining all such power systems. There was pneumatic operation of brakes, pneumatic operation of guns and bomb gear on military aircraft, pneumatically-operated flap gear and, latterly, pneumatically-operated means for raising the undercarriage; so that, provided the engine was equipped with an air compressor and suitable reservoirs, he believed that there was a very good case for the pneumatic system, since it was likely to prove the lightest installation of all. Of course, time might alter that position, but he believed that at the moment pneumatic operation of retractable undercarriages was worth the attention of designers. He was also interested to hear that Mr. Tiltman's experience with flexible piping confirmed his own earlier troubles, although he now felt that the hydraulic system was thoroughly reliable when properly maintained and all flexible hose eliminated in favour of steel or copper piping.

Dealing with Mr. Cornwall's reference to the drag of a clean undercarriage as against a retractable version for the same machine, he had always contended that speed tests on aircraft with retractable undercarriages were somewhat misleading because undoubtedly the differences in speed were recorded with what could only be described as a very dirty undercarriage in the extended position, thus masking a true comparison with a clean cantilever design. Indeed he had been careful to point that out in the paper itself, for he was fully aware that such comparisons were likely to give a distorted view of the picture and he regretted that reliable full-scale figures on this point were so scanty as to be hardly worth quoting. About the best report on the problem, to his knowledge, was contained in U.S. Air Corps Information Circular No. 678, but this official analysis was now some three years old. He would be glad to see more recent data from our own official sources, because the problem was full of pitfalls for the designer seeking fact from fancy. Several recent N.A.C.A. Reports on the drag of full-scale undercarriages were a most illuminating contribution to the subject and he regretted that our own Research Committee seemed to be unaware of designers' needs in this field. As a rough and ready assessment of the *true* speed increase due to undercarriage retraction (*i.e.*, when 100 per cent. retracted), he had estimated in several cases that about two-thirds of the increase might be legitimately credited to retraction, the remaining one-third being due to the elimination of the extreme dirtiness caused by unfaired chassis structure, fairing shields, etc., present in the take-off and landing condition.

With regard to Major Green's request for information concerning the weights of retractable undercarriages, he said he had reluctantly refrained from tabulating weight figures in the paper because of the unreliability of the data at his disposal. For instance, in some of the American figures there had been included not only the weight of the undercarriage proper, but also that of the tail wheel unit, and it had been difficult to break down the figures on a comparable basis. According to the American Air Corps report already mentioned, the retractable gears varied widely from 5.0 to 6.5 per cent. of the gross weight of the aeroplane; the cantilever gears bracketed between 5.8 and 7.6 per cent.; while the fixed types ranged from 4.6 to 5.7 per cent. Speaking generally, he would estimate that the cost of a retraction scheme would run between 1 and 2 per cent. addition to the gross weight, but it really depended upon so many other influencing design factors. Thus in the case of the Douglas transport, he had seen quoted the figure of 5 per cent. for the complete undercarriage, plus power mechanism and hydraulic installation, whereas the Vultee transport with its heavier cantilever construction and total retraction into the wing profile came up to about 7 per cent. of the gross weight. In the case of the Vultee, however, it should be remembered that the electric motor was also used to drive the wing flaps. He hoped to be in a position to add further details regarding weights of these two undercarriages.

Referring to Mr. Langley's suggestion to inter-connect the shock absorber strut and retracting jack as one combined mechanism, he had already given some consideration to the problem, but personally he did not think that the extra complications were justified, although he believed that Sikorsky in America had used the idea on some of his amphibian boats. With pneumatic shock absorbers there seemed a possibility that any inefficiency on the part of the retracting gear might reflect itself as a loss in the efficiency of the shock absorbing medium. Regarding the question of weight comparison of retractable versus cantilever types, it was hardly fair to compare the cantilever undercarriage of a light aeroplane in the 2,000lbs. class with a power-operated retractable gear (and cantilever at that!) on an 8,500lbs. transport machine such as the Vultee. As to the fitting of a retractable mechanism to a small two-seater light plane, he was strongly inclined to agree with Mr. Langley's views, since the economics of the case were very different from that of the transport machine operating at high

cruising speeds. On the other hand, he could not agree with Mr. Langley's implied suggestion that we in this country designed our undercarriages on a more robust basis due to the requirements of our rougher aerodromes, because from his own examination of American undercarriages he would be inclined to say that the Americans designed to higher factors than the British.

In reply to Mr. Gordon England's request for further data on the economics of undercarriage retraction, he said that that was principally the concern of the aircraft constructor rather than the specialist designer of components. He confessed that the paper was presented more particularly from the latter angle because, of course, that was his side of the job, and he was prepared to cut his cloth to order. Perhaps it would be true to say that he was accepting the *fait accompli*, as it were, rather than pleading a case for retraction, which he felt was unnecessary at this advanced stage of the art, as witness the overwhelming evidence of transport operators in the States. One must recognise that American transport interests were a very commercially minded group and it was plain that they had been sold the idea on a dollar basis. A very interesting analysis somewhat on the lines asked for by Mr. England was contained in an article on "Retractable Landing Gears," by R. M. Mock, in *Aviation* for February, 1933. All the same, however, he freely admitted Mr. England's contention that the game was hardly worth the candle on many small machines of low power and moderate performance. The private owner, for example, was likely to shy at the increased maintenance involved.

Regarding the other point raised by Mr. England on the method adopted for retraction, there appeared to be some confusion of terms, especially the conception of a mechanically-operated gear. In the paper, he had broadly divided operating systems into two groups, viz., manual operation and power operation, the manually-operated systems being further sub-divided into mechanical gears (*i.e.*, cable and pulley, screw and nut, etc.), and hydraulic systems depending on a hand pump, oil pressure lines and lifting jacks. When the speaker referred to mechanical retraction, he (Mr. Dowty) assumed that he meant some form of power motor was employed. He had endeavoured to show that manual operation was not a favourable proposition *above* a certain gross weight, but below that figure on small aircraft it came back to a question of pounds weight and pounds sterling. Granted that the aircraft designer was prepared to carry the added weight and cost of a power-operated mechanism, he was in thorough agreement with Mr. England's views regarding its value at the take-off; the sooner one could get a dirty gear tucked up out of the way, the better.

Mr. Manning evidently disagreed with such a practice, but it appeared to have become the standard procedure on American transports according to reliable observers. The Vultee, at any rate, was capable of meeting this condition without undue hazard by reason of its worm-gear construction, and the same was probably true of most of the forward retraction schemes described in the paper. Regarding Mr. Manning's request for more detailed weight data, he was sorry that he could not add any information other than that already given in reply to Major Green. He believed that the brake torque on the Douglas chassis was taken through the radius rod, but he was not sure on that point and would check it up with Mr. Evans.

It was very difficult at short notice to reply to Mr. Lyon's question as to whether retractable undercarriage failures were due mostly to poor design, bad maintenance, forgetfulness on the part of pilots, or any other outstanding cause. But a case prominently in his mind was one in which failure was due to inaccurate recording of the actual position of the undercarriage, the pilot having landed when the indicator had signalled the down position, when in fact the undercarriage was not so. He had been told that quite a lot of accidents abroad had been due to some simple detail matter rather than major mechanical troubles or fractures. However, it would be most instructive to have an analysis of undercarriage

failures, and he joined with Mr. Lyon in hoping that the Air Ministry might see their way clear to provide such information in the interests of the whole industry.

Dealing with Mr. Clegg's remarks on shock absorber struts, he said it was quite true that with the retractable undercarriage there had been a major change in the design of the shock member, and it was easy to see why. A few years ago, when the shock strut was a pin-jointed member, there were possibilities of introducing a certain amount of free travel. In the narrow track undercarriage a short travel on the springing was necessary in order to keep the aircraft from swinging and to prevent either of the wing tips from touching the ground when the machine was turning. But with the introduction of retractable undercarriages—which generally meant a much wider track—very often one had a system of duplicated shock struts, one on each side of the wheel, hence free travels were not possible owing to the probable unequal extensions of the shock absorbers. In that case, if one resorted to steel springs for the shock absorption, the units would be unduly heavy and probably produce bouncing during the taxying condition. That was why the pneumatic shock absorber was possibly the best one to use on retractable undercarriages where a shock strut was mounted on either side of the wheel.

In thanking Mr. Simmonds for his kind remarks, he believed that it was not difficult for the specialist to be successful as, although the specialist exploiting new ideas tripped up every now and again and made mistakes, they were found out sooner and so any troubles which arose were diagnosed more readily. He thought that Mr. Simmonds' description of his work as a clearing house was very apt, for it was his privilege to view a most interesting cross-section of the industry.

He was also glad to have this further opportunity of thanking Mr. Evans, especially for his remarks on American practice and his spirited frontal attack on Air Ministry " gadgetry." Mr. Evans had been fortunate enough to be on the Douglas design staff during a period of great technical activity on the Pacific coast, hence his criticisms were to be respected. However, while sympathising a great deal with his point of view, he did not feel that the emergency lowering mechanisms, described in the paper, warranted the title of " funk mechanisms "; at any rate, until we on this side had had a little more experience of retraction schemes in daily operation. Both the power and manual systems of operation used the same reservoir and pipe line circuit, hence in military machines if a pipe line or the reservoir was crippled the emergency means might be found exceedingly useful. Furthermore, the criticism of added weight was somewhat discounted, since in one of the schemes shown the increase was of the order of a few ounces only. On the other hand, he admitted that it inevitably introduced a certain amount of extra complication, which must be faced in the interests of our British characteristic of " safety first." All the same, he joined with him in his admiration of American engineering technique in the development of the retractable undercarriage to a practical commercial stage, but he thought that even Mr. Evans would admit that we were now rapidly catching up in that direction.

Commenting on the Chairman's question as to whether a folding undercarriage should be referred to as " retractable " or " retractile," he said that he had been rather expecting that one, so he had taken the precaution of consulting a couple of dictionaries before coming there that evening. One of these defined " retractable " as " capable of being retracted," and " retractile " as " capable of being drawn back, as claws," so there really seemed little to choose between them; in any case, both forms had their genesis in the same Latin root, *retractum* (I draw back). Perhaps the word " retractable " might be construed as more applicable to the retraction of words or acts (*i.e.*, a recantation or a disavowal), but, on the other hand, one did not always draw an undercarriage backward like the birds, so he had been weak enough to fall into line with common usage. Both here and in America, the " retractable " form had been applied to

the mechanical act of stowing away an undercarriage in flight for something like twenty years, so he had given it preference over " retractile." Incidentally, he suggested that the word " retractor " might be adopted as a suitable description for the lifting mechanism itself; thus in hydraulic systems, the jack would become the retractor.

Finally, in reply to Mr. Boultbee's contribution, while he was sometimes painfully aware of the difficulties and complications inherent in the development of retractable undercarriages, he thought that Mr. Boultbee was unduly pessimistic of the future. It was surely a little late in the day to damn their use in face of the successful experience of commercial operators in the States. With more intensive development work he was quite confident that all the snags could be defeated. We had heard the same arguments applied to wing flaps, slots and variable pitch airscrews, but the history of the past few years showed that we had merely succeeded in rolling back the tide of progress from the old world to the new. Furthermore, he had rather a suspicion that Mr. Boultbee was talking with his tongue in one cheek because he had been largely responsible for the retractable undercarriage of the Klemm " Eagle," and he (Mr. Dowty) looked upon that job as a particularly neat solution of the problem. He thought, therefore, that Mr. Boultbee's design experience pointed along the same path as his own, so he looked forward to his next contribution to the art.

On the motion of the CHAIRMAN, a hearty vote of thanks was accorded Mr. Dowty for his paper.

NOTES ON THE STRENGTH OF STRESSED SKIN FUSELAGES

BY

G. F. WALLACE, A.F.R.Ae.S.

With the growing popularity of the stressed skin or monocoque fuselage it is thought that the following notes may be of interest. There are many advantages in using stressed skin construction, but one reason against it in the past has been the difficulty in accurately calculating the strength of such structures. Sufficient information has now been accumulated, however, mainly from American sources, to enable the designer to obtain a fair idea of the strength of stressed skin structures, although the stresses occurring under any system of loads cannot be calculated at present with the same certainty as for the conventional braced structure. In the braced frame fuselage the loads are taken by struts and tie rods in tension and compression, but in the stressed skin fuselage they are taken as bending and shear loads in the skin. Once the ultimate tension and compression stresses are known for the material used, the strength of the struts and tie-rods for any system of braced structures is easily calculated. In the stressed skin structure, however, the ultimate stresses for the material are never realised over the whole structure, as failure invariably occurs through local buckling of the skin. The question is further complicated by the fact that the stress at which local failure will occur in sections built of thin plate varies with the design of the section, and two sections having the same area and same moment of inertia would not necessarily develop the same stress in bending.

The true monocoque fuselage consists of a thin cylindrical shell stiffened at intervals with circular rings; this type of construction has been used, but in order to make the skin carry higher stresses it is usually stiffened by longitudinal stringers, and this is the most common form of stressed skin fuselage and is shown in Fig. 1. The transverse rings vary in section according to their position

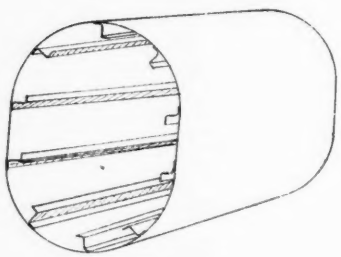

FIG. 1.

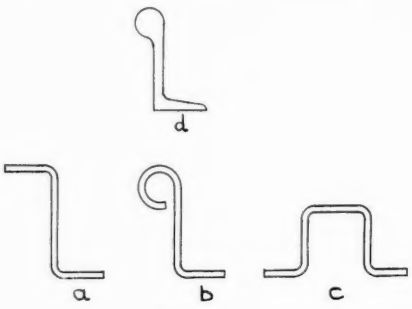

FIG. 2.

in the fuselage, those taking concentrated loads, as at the wing spars, are usually heavy built up sections, but those in the region of the tail, whose chief function is to maintain the shape of the fuselage, can be light channel or angle sections. The longitudinal stringers are usually one of the types of section shown in Fig. 2. Types (*a*) and (*b*) are the cheapest to produce, but under

compression liable to local failure by the outer edge bending in the plane of the skin; type (*c*) would develop the highest stress, but entails two lines of rivets; while type (*d*), which is an extruded section, is the most efficient, but is the most expensive to produce.

The strength analysis of stressed skin fuselages resolves itself into three main problems, the estimation of the shear strength of the panels, the estimation of the compressive strength of thin panels, and the investigation of the bending and shear stresses in the transverse rings or frames under various systems of external loads.

The shear stresses in beams having very thin webs has been investigated by Dr. Wagner, of Danzig, Germany, and his results have been made accessible to the English public in N.A.C.A. Technical Note No. 469,* from which the following formulæ have been taken.

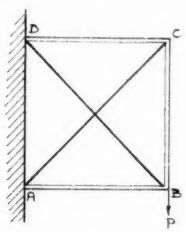

FIG. 3.

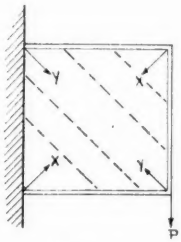

FIG. 4.

Consider the wire braced panel *ABCD* shown in Fig. 3 under the action of a small load *P* member, *AC* is in compression and member *BD* in tension; if *P* increases *AC* soon becomes unstable and buckles and the entire load is then taken by *BD* in tension. Now consider the wires replaced by a panel of thin material, as in Fig. 4, the load *P* will put compressive stresses in the panel in the direction of *x* and tensile stresses in the direction of *y*. Under the action of the compressive load the panel buckles into folds at very low values of *P* and the load is then taken entirely as a tension in direction *y*. The folds run diagonally across the panel as indicated by the dotted lines in Fig. 4, and these folds are termed a "diagonal tension field" and the tension stresses in them as "tension field stresses." The general and particular cases of tension field stresses in thin webs are fully treated in N.A.C.A. Technical Note 469, but the most important case in the treatment of stressed skin fuselages is reproduced here. This is the case of a beam with parallel flanges and vertical struts which are infinitely stiff in the plane of the panel. The angle α which the tension field folds make with the flanges can be shown theoretically to be a few degrees less than 45°, but it is sufficiently accurate to assume 45°. Such a beam is shown in Fig. 5.

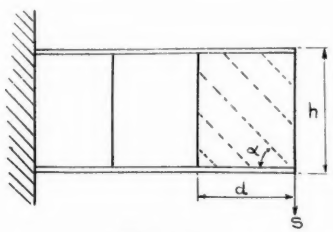

FIG. 5.

* A summary of design formulæ for beams having thin webs in diagonal tension. Paul Kuhn.

If f = tension field stresses,
$H_{T,C}$ = tension and compression in flanges,
V = loads in strut due to tension field,
t = thickness of panel,
S = shear at point considered.
M = moment at point considered,
h and d are as in Fig. 5.

Then Dr. Wagner gives

$$f = 2S/ht \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$H_{T,C} = \pm M/h - \tfrac{1}{2}S \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$V = -S\,(d/h) \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If the struts are flexible in the plane of the panel the tension field stress becomes

$$f = (S_L + S_R)/ht \pm Pn/dt \quad . \quad . \quad . \quad . \quad . \quad (4)$$

In the case of a beam with non-parallel flanges the loads given by equation (2) are the horizontal components of the flange loads and the load in the direction of the flange is easily calculated when the inclination of the flange is known. The vertical components of the flanges carry part of the shear and the shear carried by web is

$$S_W = S - (M/h)\,(\tan\delta T + \tan\delta C) \quad . \quad . \quad . \quad . \quad (5)$$

where δ = angle of inclination of flange and S_W can be used to calculate the web tension as for beams with parallel flanges, the average value of h for the bay being used. This method is only approximate and its accuracy varies inversely with the inclination of the flanges and should not be relied on if the inclination is large.

If the flanges are infinitely stiff and the struts spaced between one-sixth and one-half of the depth of the beam, the maximum bending stresses in the flanges due to the normal component of the tension field are given by

$$M_F = (Sd^2/12\,h)\tan\alpha \quad . \quad . \quad . \quad . \quad . \quad (6)$$

and occurs at the strut.

If the flanges are flexible or the struts are widely spaced the diagonal tension is only developed over a width Δd of the web. This causes a reduction in MF to MF_1, where

$$MF_1 = C_1 \times MF \quad . \quad . \quad . \quad . \quad . \quad (7)$$

When only a portion of the web is working equation (1) gives the average stress in the web and the maximum stress is given by

$$f_{max} = f/C_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Δd, C_1 and C_2 can be read off curve in Fig. 6 as functions of wd.

$$wd = 1.25\,d\sin\alpha\,\{\,t/(I_T + I_C)\,h\,\}^{\frac{1}{4}} \quad . \quad . \quad . \quad . \quad (9)$$

where I_T and I_C are the moments of inertia of the tension and compression flanges about their own neutral axes.

In practical design it is frequently necessary to have fairly large holes in the shear panel for windows, inspection, and such like purposes. These affect the strength of the panel considerably, but so far no mathematical treatment of this question has been published. Consider the shear panel in Fig. 7*a* with a circular hole in the middle and the edges of the hole stiffened by a ring. The tension field folds are cut at the ring and impose loads in the plane of the plate, as shown; if the deflection of the ring in the plane of the plate, under these loads, is the same or less than the deflection of the tension field folds, then the strength of the panel is unaffected by the hole. If, however, the ring deflects more than the tension field in the direction of the folds, the tension field folds cannot develop their maximum stress and the strength of the panel depends on the strength of the ring in bending. From this it would appear that the best way

of stiffening such holes is by means of a series of laminated rings as in Fig. 7*b*, while stiffening such as that shown in Fig. 7*c* is of little use. This is shown to be correct in a series of experiments described by Mr. H. J. Pollard in the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY of July, 1934.

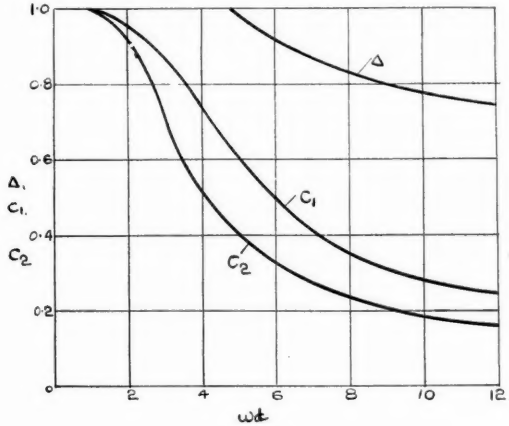

FIG. 6.

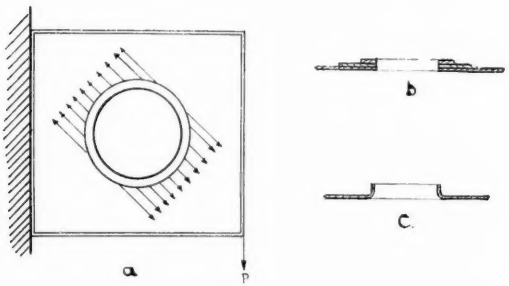

FIG. 7.

Tension field theory can be applied to deal with the effect of holes on the torsional strength of monocoque structures. A bay on a monocoque fuselage is shown in Fig. 8 with a hole in the side, the edge of which is stiffened with a ring. If the hole is ignored in the first instance and a torque T is applied to the

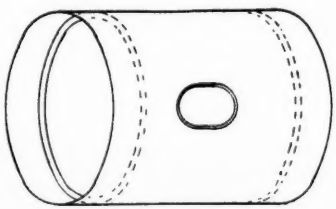

FIG. 8.

structure, then the shear per inch round the circumference of the section is given by

$$s = T/2A \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where A is the area enclosed by the section in sq. inches.

If C is the circumference of the section and d the distance between the two stiffening frames, then the bay can be considered as a Wagner shear panel "d" wide by "C" deep with flanges infinitely stiff and carrying a shear equal to

$$S = CT/2A \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

The tension field stress is then

$$(2CT/2A)/Ct = T/At$$

Mean shear stress is

$$T/2At$$

Hence the tensile stress is twice the mean shear, which is in accordance with theory. Now consider the effect of the hole, the section can now be treated as a shear panel of depth C-W, where W is the width of the hole, and carrying a shear of

$$CT/2A \text{ as before.}$$

The flanges are no longer infinitely stiff, but are formed by the reinforced edges of the hole, and by using the I of the reinforcing flange in equation (9) the new tension field stress and the bending in the reinforcing can be calculated.

A difficult point in the design of shear panels is to decide the maximum tension field stress that can be worked to. The tension field would obviously develop the ultimate tensile stress of the material before fracture, but long before this stress could be developed in the tension field, the stresses due to compression at right angles to the tension field would have exceeded the elastic limit and the folds would have become permanent. A structure with permanent folds in the tension field would probably be quite safe, but it is obviously undesirable for aerodynamic and psychological reasons to have permanent corrugations in fuselage or wings.

The maximum stress that can be worked to is obviously that at which the tension field folds become permanent. This can only be accurately determined by experiment, and no such experiments have as yet been published. It is possible, however, to obtain indirectly a rough idea of the compressive yield stress for tension field panels. In N.A.C.A. 356* results are given of experiments on thin rectangular plates under edge compression, with all four edges simply supported. In event of the two loaded edges being fixed the stress developed would increase in the ratio 4:7, and working on this assumption the figures in N.A.C.A. 356 have been modified for a plate with fixed edges and a curve of yield stress against plate thickness for dural plates is given in Fig. 9. These figures would hold approximately for the compressive stresses in tension field panels and give an approximate basis for design pending the publication of more accurate information; they are probably on the pessimistic side.

It is possible that higher stress than the yield stress in compression is developed before the tension field folds become permanent, for, although the material may have exceeded the yield in compression, the tension field is still within the elastic limit and when the load is released the energy stored in the tension field would pull out the folds. If the panel is subjected to a fluctuating load it would be advisable to keep the working stress well below the yield or the material would rapidly fatigue.

Another important problem in monocoque design is the question of compressive stress in thin plates. Tests described in N.A.C.A. Report 356 show that for thin plates between 22 g. and 18 g., 24in. long, the maximum stress is developed with plates 4in. wide, and any further increase in width gives little

* Strength of rectangular flat plates under edge compression. Louis Schuman and Goldie Back.

or no increase in the maximum load carried. The plates fail through instability in a plane at right angles to the plane of the plate and to overcome this in most monocoque structures the plate is stiffened at intervals by means of stringers, usually one of the types shown in Fig. 2.

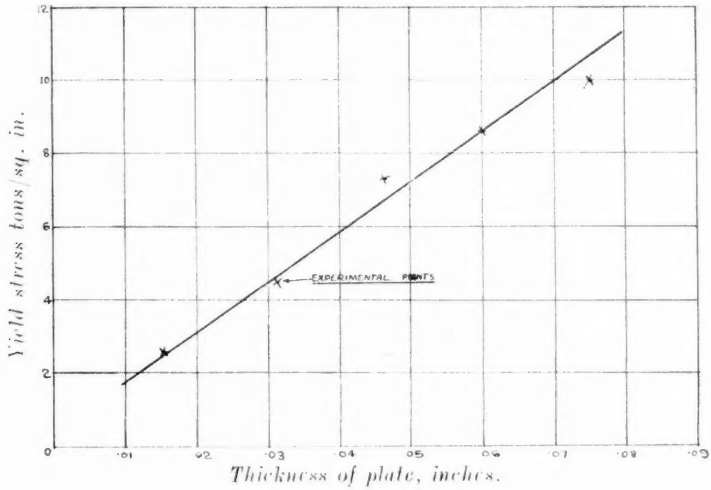

FIG. 9.

The strength of thin plates subjected to compressive loads and stiffened by stringers parallel to the direction of the loads is discussed in N.A.C.A. Technical Note 455,* in which it is concluded that the most satisfactory way of obtaining the strength of such plate and stringer combinations is to assume that the entire load is taken by the stringers and a certain width of plate attached to them working as a strut and failing by bending in a plane normal to the plate. When the plate between the stringers starts to buckle the stress distribution is as shown in Fig. 10. Von Kármán gives the following equation for

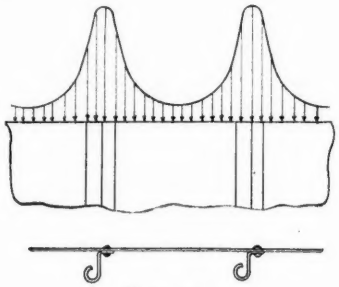

FIG. 10.

obtaining the effective width w of plate acting with the stringer:—

$$w = Kt\sqrt{(E/f)} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

* Comparison of three methods for calculating the compressive strength of flat and slightly curved sheets and stiffener combinations. Eugene E. Lundquist.

where f = stress in stringer in lbs. per sq. in.
t = thickness of plate.
K = a constant.

As a result of tests K is given as 1.7 for that portion of the plate between the adjacent stringers and as 1.0 for that portion which lies outside the rivet lines of the two edge stringers. The area and radius of gyration of the section formed by stringer plus effective width of plate is calculated, and if the length of the plate is known the strength can be calculated from the standard strut curves for the material used.

Tests on plate and stringer combinations under compressive loads quoted in N.A.C.A. Technical Note 455 show very close agreement with the ultimate loads calculated by the above method. It is also shown by tests that slight curvature of the plate normal to the length of the stringers has no appreciable effect on the maximum load carried, but with thick plates with the curvature varying along the length of the stringer the strength may be reduced by 10 or

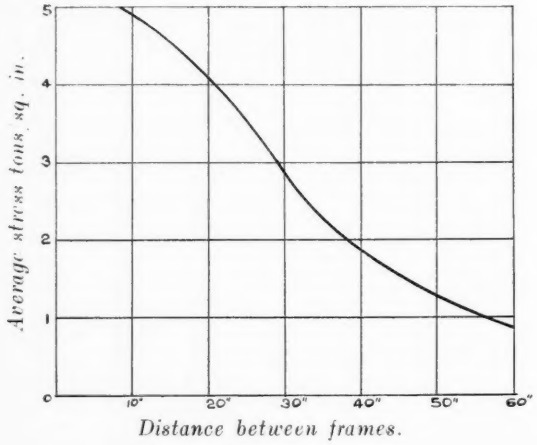

FIG. 11.

15 per cent. The optimum spacing of the stringers is at present a matter of personal opinion and no investigations on the subject have as yet been published. From the results in N.A.C.A. 356, it would appear that in order for the entire plate to develop equal stress the spacing should be about 4in. for thickness between 22 g. and 18 g. and 6in. to 8in. between 16 g. and 12 g. In practice this close spacing would not be economical and much wider spacings are usually adopted. It is obvious that the closer the spacing the smaller the load carried by each stringer, and also as the stringers act as struts, that within limits, the shorter the stringer the greater the load it will carry. From this it follows that in a monocoque fuselage the stringer spacing and the frame spacing are to a certain extent interdependent, and that as the stringer spacing increases the frame spacing must decrease and vice-versâ. It would probably be easier to standardise stringer spacing than frame spacing, and if a certain type of stringer were standardised and the stringer spacing standardised it would be possible to construct curves giving the maximum compressive stress in the plate for variations in frame spacing. Fig. 11 shows a curve with maximum stress plotted against distance between frames for 18 g. plate stiffened with the stringer section of channel $1\frac{1}{4}$in. × $\frac{9}{16}$in. × 18 g. and with a spacing of 8in.; the stress is the

average stress defined as the total load acting on any section of plate divided by the total area of the section, including all plate and stringers, and does not represent the actual stresses developed in individual parts of the plate and stringer combinations. When applying Von Kármán's equation to find the compressive stresses due to bending in a monocoque fuselage the following procedure is adopted. The moment of inertia and neutral axis of the section of the structure under consideration is calculated and the maximum compressive stress at the outer edges is obtained, assuming that the entire plate is taking load. The load on the plate and stringer combination is obtained by multiplying the stress by the area of the stringer plus area of plate between two adjacent stringers, *i.e.*,

$$P = f(A + xt) \quad . \quad . \quad . \quad . \quad . \quad (13)$$

where P = load on plate and stringer combination.
f = average stress in lbs. per sq. in.
A = area of stringer.
x = stringer spacing.
t = thickness of plate.

The next step is to find the effective width of plate. Let f_1 be actual stress in stringer, then

$$f_1 = P/(A + wt) \quad . \quad . \quad . \quad . \quad . \quad (14)$$

and from (12)

$$w = 1.7\, t \sqrt{(E/f_1)}$$
$$\therefore\ w = 1.7\, t \sqrt{\{E(A + wt)/P\}}$$

and this reduces to

$$w = \sqrt{\{[A + (1.7^2 \times t^2 \times E)]/P + (1.7^2 \times t^3 \times E)^2/4\}} + \sqrt{\{(1.7^2 \times t^3 \times E)^2/4\}} \quad . \quad . \quad . \quad . \quad (15)$$

The area and radius of gyration of the plate and stringer combination is found and the maximum load carried is obtained by assuming the plate and stringer combination to be a strut of length equal to the distance between the two frames of the fuselage section considered.

The method of applying the equation given to any type of stressed skin construction can be varied to suit individual requirements, but to illustrate their use a hypothetical example is worked out below.

Consider the section of a monocoque fuselage shown in Fig. 1. The distance between the frames is 22in., the skin is 18 g. duralumin and the stringers are of the section shown and spaced 8in. apart; the section is subjected to a shear of 14,00lbs. ins. and A.B.M. of 2,000,000lbs. ins. at the mid-distance between the frames. The AI and Z for the section are first calculated, these are

A 10.3 sq. ins.
I 7,300 ins.^{3}.
Z 187 ins.^{2}.

Maximum bending stress in section

$$= 2{,}000{,}000/(2{,}240 \times 187) = 4.75 \text{ tons/sq. in.}$$

This represents the average stress in the plates and stringers at the top and bottom surfaces of the fuselage. The stringer spacing is 8in.; that is, 8in. of plate per stringer, therefore load on plate and stringer combination

$$= 4.75\,(8 \times 0.048 + 0.11) \times 2{,}240 = 5{,}250\text{lbs.}$$

$\therefore$ Effective width of plate

$$= \sqrt{\{(1.7^2 \times 0.048^2 \times 10.5 \times 10^6 \times 0.11)/5{,}250 + [(1.7^2 \times 0.048^3 \times 10.5 \times 10^6)^2/5{,}250]/4\}} + \sqrt{\{[(1.7^2 \times 0.048^3 \times 10.5 \times 10^6)^2/5{,}250]/4\}}$$
$$= \sqrt{(1.47 + 0.102)} + \sqrt{0.102}$$
$$= 1.57\text{in.} \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Area of combined section

$$= 0.11 + (1.57 \times 0.048) = 0.185 \text{ sq. ins.}$$

$$K = 0.495$$

$$\therefore\ L/K = 22/0.495 = 44.5.$$

From standard strut curves for duralumin

$$P/A = 29{,}500 \text{lbs./sq. ins.}$$

$$\therefore \text{ Safe load} = 5{,}450 \text{lbs.}$$

The shear load is considered to be taken by the sides of the fuselage and the length of side A-B in Fig. 1 is assumed to be effective.

From equation (16)

$$\text{Stress} = (2 \times 14{,}000)/(2{,}240 \times 60 \times 0.048) = 4.34 \text{ tons/sq. ins.}$$

and compressive load in frames

$$= (14{,}000 \times 24)/60$$

$$= 5{,}600 \text{lbs.}$$

In conclusion, it must be emphasised that the methods described above are in no way final, but represent as close an approximation as is possible in the present state of published knowledge.

ENGINEERING PROBLEMS IN AIRCRAFT OPERATION AT HIGH ALTITUDES*

BY

R. E. JOHNSON† and R. F. GAGG,‡ Paterson, N.J.

The authors review the capabilities of the typical modern airplane for high-altitude operation and present the restrictions of the power plant of the modern airplane which prevent it from delivering its normal output at high altitudes. The paper also discusses the improvements in the aerodynamic characteristics of the airplane as well as changes in the power-plant design and the progress achieved in cruising operation at high altitudes within the limitations imposed by passenger comfort and safety. The authors evaluate further possible gains which may result from an extension of this trend, and examine the engineering problems involved in both the airplane and the engine.

The striking changes in aircraft performance obtained in the past five years have resulted from material improvements in aerodynamic characteristics, as well as from changes in the power plant. Previously, the latter factor appeared to be nearly the sole means used for improving performance, and the results were rather disappointing, as would be expected from consideration of the simple mathematical relations between speed and power. The quest for increased speed in commercial air transport has turned from a consideration of increased power and improved aerodynamic qualities to a study of the advantages obtainable by extending the cruising operation to higher altitudes. Substantial progress has already been achieved in this manner within the limitations imposed by passenger comfort and safety in present types of equipment, and it now seems in order to evaluate further possible gains which may result from an extension of this trend, and to examine the engineering problems involved in both the airplane and the engine.

The typical modern airplane is capable of normal flight operation at altitudes far higher than any now utilised if a suitable power plant were available which could deliver its normal power output at any altitude. Since the restriction of primary importance is in the power plant, that problem is considered before counting the gains which might be realised without this limitation.

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NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Engine Performance Ratings

Three kinds of ratings are required for engines intended for service in high-altitude aircraft. These are (1) take-off rating, based on the maximum permissible power output for short periods at low altitudes; (2) maximum power for protracted periods, which power is to be used to reach destination in event of failure of one or more power-plant units and not for normal operation for long periods; and (3) cruising rating, which rating requires maximum power for continuous normal operation.

In order to provide a quick and safe take-off, it is desirable that the take-off rating be 150 per cent. of the cruising rating. This large margin of reserve power will enable the airplane to operate from small airports, and also provides a factor of safety for emergencies. The intermediate rating, termed the maximum power for protracted periods, is not normally required in airline service, and is used only in case of a continuing need for a maximum of power consistent with safe operation, such as the failure of one unit in a multi-engined airplane. This high-power rating obviously is required only at altitudes where some high land may be encountered in the flight path. The cruising rating and the limiting

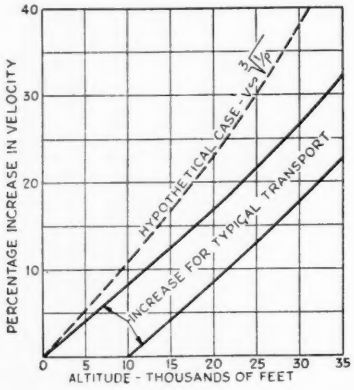

FIG. 1.

Change in Velocity of Level Flight with Constant Power for Various Altitudes.

height at which that power can be maintained are the most important measures of the usefulness of an engine for high-altitude operation. When used in the same kind of airplane, the same speed will be obtained with a 500 h.p. engine at 12,000ft. altitude or an engine giving 330 h.p. at 35,000ft. In terms which have a greater appeal for the American operator, if the 500 h.p. were maintained to 35,000ft. the speed would increase by about 23 per cent. These relations are illustrated in Fig. 1 for a modern transport airplane. Without considering other important factors, it would, therefore, appear that unlimited upward extension of the altitude limitation of cruising power would be desirable. Notable progress has been achieved in this direction as the related problems of durability and power output, supercharging, combustion control and cooling, and fuel consumption have gradually been disposed in harmonious balance. Fig. 2 shows changes in the ratings of a typical American engine resulting from assiduous demands for greater power output and increased altitude performance with improved durability. A brief examination of current limitations on further progress will indicate what may reasonably be expected from the engine in the

near future and thus establish the field immediately to be considered for high-altitude flight.

Assuming that the engine design is properly proportioned with respect to strength, heat flow, and lubrication, its cruising rating will be established in practice at the highest level which will permit operation without major failures in a period of 350 to 400 hours between overhauls. In other places it is sometimes the practice to operate at a lower output and stretch the overhaul period, but this is scarcely to be expected in American operations. Types of engines now available are capable of cruising ratings of 0.25 to 0.33 h.p. per cu. in. of displacement, and the upper value is likely to change but slowly for a considerable period unless radical departures in engine design are encountered.

Engine Supercharging

With a supercharger of the centrifugal-compressor type driven from the engine crankshaft at a fixed gear ratio, it is feasible to maintain the cruising power rating up to about 14,000ft. altitude and still obtain acceptable take-off performance with present types of fuel. This range can be somewhat extended with the aid of an intercooler, though the additional drag, weight, and complication do not appear to justify its use. The limitation of the single-stage supercharger just mentioned is encountered at sea level at the take-off condition. The liberal use of fuel cooling and tetraethyl lead in the fuel during take-off has considerably extended the useful range of this type of supercharging, but even with benefit of much improved cooling practice and better fuel it is apparent that the difficulties encountered under take-off conditions will place a relatively low limit on its utility for high-altitude aircraft.

A second geared centrifugal compressor used only at high altitudes to supplement a primary unit of the type just discussed has been used successfully to obtain additional altitude performance with conventional engines. This type of unit has all of the advantages of the single-stage unit at low altitudes plus the ability to maintain the cruising rating to about 25,000ft. altitude without the use of an intercooler. This improvement in performance can be obtained without material increase in the airplane drag, though it does require a somewhat higher specific fuel consumption due to the increased power absorbed by the supercharger.

Many of the advantages of both the dual-compressor unit and the integral, single-stage supercharger can be realised by the incorporation of a two-speed transmission with suitable clutching in the gear drive for the integral type of centrifugal supercharger. Such an arrangement permits optimum sea level performance for take-off, and by changing the speed of the supercharger impeller, gives adequate supercharging for high-altitude cruising.

The second or high gear ratio may be chosen so that the supercharger compression ratio is the maximum that can be used with the engine and fuel selected without encountering detonation in cruising. Assuming the same compressor efficiency in each case, the altitude limitations of the two-stage compressor and the two-speed single-stage compressor are, therefore, identical without intercooling, and the latter refinement scarcely seems warranted in the face of the high penalties which its use imposes. For the ultimate maximum in degree of supercharging, two-stage compression with an intercooler may prove to be necessary, but until the means otherwise available have been exhausted this complication should be avoided.

The combination of one supercharger stage gear-driven from the crankshaft and another stage driven by an exhaust gas turbine may be compared fairly to the two-stage gear-driven combination. The low-altitude performance ratings may be obtained by the use of the gear-driven supercharger only, exactly as in the cases previously considered, and the turbine unit may be used at high altitudes to maintain the cruising-power output. Due to the fact that the turbine speed, and hence the supercharger compression ratio, is subject to control, the required

power may be obtained at intermediate altitudes with a little lower charge temperature than that obtained with the two-stage gear-driven unit.

It seems probable that the combination gear and turbine-driven two-stage supercharger will give excellent performance at very high altitudes, but the complication of the dual type installation plus the practical problem presented by an exhaust manifold operating at an unusually high temperature and pressure are obstacles which may block its progress. Moreover, there is no conclusive evidence to prove that the results obtained without intercooling cannot be matched by a two-stage geared supercharger. These handicaps appear to preclude its wide adoption in the immediate future.

The exclusive use of an exhaust-turbine drive for the supercharger at all altitudes does not appear to be particularly attractive because of the difficulty of obtaining a very high output for take-off at sea level without encountering prohibitive temperature and pressure in the exhaust system and cylinders.

It is unfortunate that necessary experimental data are not available as a basis for completely evaluating the merits of the turbo-supercharger. However, it seems probable that this type, when used with adequate intercooling, will produce the highest power output at altitudes above 30,000ft.

For the near future, it therefore appears to be feasible to employ either two-stage compression or a two-speed supercharger drive which will permit attainment of adequate power ratings for take-off and emergency service at low altitudes with the lower of the two degrees of supercharging, and to maintain the cruising-power rating only to about 25,000ft. altitude with the other combination. Such an engine requires the use of a propeller that is completely controllable and a governing mechanism to maintain the engine-operating speed at suitable values. With this arrangement the maximum airplane cruising speed will be obtained at 25,000ft. and the speed at 35,000ft. altitude will be about 94 per cent. of the maximum. This range would normally be used for cruising operation, and if circumstances require low-altitude running, the engine will be well adapted for operation at the same cruising rating near sea level.

Consideration of the numerous variables which need to be controlled under the wide range of operating conditions indicates that unless intercooling is necessary to obtain the required output, the optimum of performance can only be realised through use of a variable-compression supercharger with complete control of its operation in flight.

Satisfactory Cooling Attained with Supercharging

An improved comprehension of the means for controlling combustion and cooling in aircraft engine practice has effected an increase in the performance attainable with a given fuel both at sea level and higher altitudes, as is shown by the curves of Fig. 2 for the period 1930 to 1935. Modern engines generally operate at temperatures equal to or lower than those commonly experienced in 1930 in spite of higher specific power output. It is interesting to note that expected difficulties with the cooling of supercharged engines in general have not been realised in practice, except in cases where abnormally low air speeds were encountered, as in high power output at very low airplane speeds. Normal airline operation fortunately does not require this low-velocity climbing, and, as previously mentioned, the cruising-power rating is the maximum required at high altitudes.

Fuel Consumption a Critical Problem

Since high-altitude flight is obviously not particularly advantageous for short distances between stops, the total propulsion weight is a matter of vital importance. This weight comprises that of the propeller, engine, cooling apparatus, installation, fuel, and oil. All items except fuel and oil in the tabula-

tion are, in general, determined by necessities of the required power output and durability. The fuel consumption at the cruising-power rating is the dominant variable in the propulsion weight figure for a flight of more than four or five hours. Actual realisation of specific fuel consumption values of 0.42 to 0.45lb. per b.h.p.-hr. under normal cruising conditions is practicable with present engines and fuels where combustion control, heat dissipation, and operating technique are properly co-ordinated. These figures are obtainable with an overall mechanical efficiency of about 88 per cent. With the same fuel-air ratio, making appropriate correction for the increase in power input to the supercharger, the same

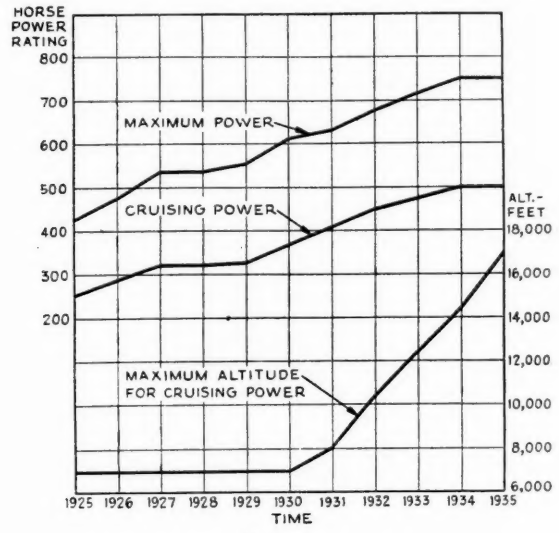

FIG. 2.

Changes in Rating of a Typical Airplane Engine.

engine when supercharged to give the cruising rating at 25,000ft. altitude will give a minimum specific fuel consumption of 0.48 to 0.51lb. per b.h.p.-hr. This severe penalty in higher minimum specific fuel consumption to attain good performance at high altitudes greatly restricts the field of usefulness of this type of engine and will result in a compromise in the selection of the operating altitude for a contemplated route schedule. However, even the values just quoted are not higher than the average experience of airline operators with present methods of control. In order to realise the minimum of fuel consumption it is necessary to install precise control apparatus and to exercise meticulous supervision. Even though the fuel consumption while cruising warrants the most precise control, to use lean mixture ratios for take-off and other high-power operation is fallacious. The richest mixture which can be employed without loss of power should be used for the take-off in order to provide a maximum factor of safety against unforeseen contingencies. In any case, the amount of fuel wasted by this procedure is insignificant for a long flight.

If fuels of improved knock rating become generally available, it will be possible to increase the compression ratios now generally used and thus improve both the power output and the specific fuel consumption. This practice will almost certainly introduce a whole new series of operating durability problems. However, a decrease of 10 per cent. in minimum attainable fuel consumption for

cruising is worth a major effort because of the resulting large increase in pay load or range.

There are undoubtedly many operating difficulties now unforeseen which will be encountered when aircraft engines begin routine service at high altitudes. The ignition system and the fuel supply problem may prove troublesome, but it is unlikely that these, or similar difficulties, will be insurmountable. Power plants suitable for cruising operation at 25,000ft. to 35,000ft. altitude appear to be feasible with fuel of 87 octane number and a conventional type of engine within a period of two or three years, but the specific fuel consumption will be relatively high because of the power consumed by the supercharger.

Time Saved by High-Altitude Cruising

Having thus broadly outlined the limitations established by the power plant for high-altitude aircraft of the near future, an estimate may be made of what changes in useful performance may be realised within these boundaries. It will be noted that the feasible modifications in the power plant previously mentioned do not involve any direct increase in drag, but only an increase in size and weight of auxiliary equipment, which probably can be accommodated within the space available in an airline transport airplane. It is reasonable, therefore, to compute the changes in performance from available data on the assumption that the basic flight characteristics of a transport airplane of modern type will not be altered materially by the installation of an advanced type of supercharged engine.

The increase in cruising speed of a transport airplane equipped with engines which will maintain constant cruising-power output to 25,000ft. is shown in Fig. 1. It will be noted that this increase in level cruising speed at 25,000ft. over that of the same airplane operating at 10,000ft. is 13 per cent. This increase will not vary greatly for any modern type of airplane with conventional wing loading. In determining the practical utility of the high-altitude airplane, the apparent increase in performance resulting from high-altitude cruising must be tempered by consideration of the trip length and schedule speed, rather than level cruising speed alone.

In order to obtain the reduction in station-to-station time possible by cruising at altitudes higher than 10,000ft., it is necessary to have certain basic performance data for the airplane, similar to that shown in Fig. 3, for the engine-operating technique normally employed. For the purpose of this analysis, the following assumptions have been made to obtain the comparative station-to-station time or speed:—

(1) A five-minute interval has been allowed for manœuvring the airplane at each end of the trip. This total of ten minutes manœuvring time has been found by experience with modern transport operation to be a necessary part of the schedule for any flight.

(2) All climbs are made with a constant-thrust horse-power which is 10 per cent. higher than the normal cruising power. It has been assumed that the engine will be capable of supplying this power to at least 25,000ft. altitude. The rate of climb is determined in the usual manner from the power required and power available curves for the airplane being considered. It has also been assumed that all climbs will be made at constant indicated air speed.

(3) All level cruising will be done at the established cruising-power rating for the engine.

(4) All glides will be made at constant rate of descent, using the rated cruising power.

Fig. 3 shows performance data for a typical modern transport airplane operating as outlined above. From these data, the station-to-station time or speed may be calculated for any trip length and for any assumed cruising altitude. Fig. 4 shows the results of these calculations for 10,000, 25,000, and 35,000ft.

cruising altitudes. Inspection of these curves will give the time saving in minutes which may be expected for any trip length for the airplane which cruises at 25,000ft. compared to the same airplane cruising at 10,000ft. with the same horse-power. This represents the real advantage in schedule time reduction available to the airline operator.

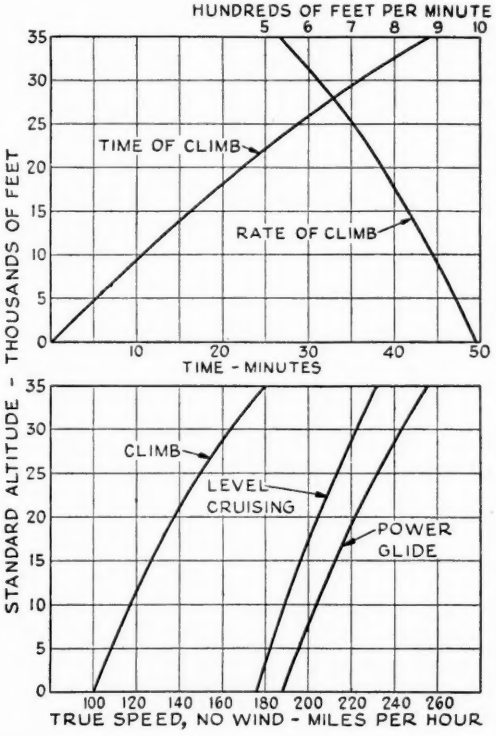
HUNDREDS OF FEET PER MINUTE
5 6 7 8 9 10
35 30 25 20 15 10 5 0
TIME OF CLIMB
RATE OF CLIMB
10 20 30 40 50
TIME - MINUTES
STANDARD ALTITUDE - THOUSANDS OF FEET
CLIMB
LEVEL CRUISING
POWER GLIDE
100 120 140 160 180 200 220 240 260
TRUE SPEED, NO WIND - MILES PER HOUR

FIG. 3.

Cruising Performance Data of a Typical Transport Airplane.

Fig. 5 shows this time saving in minutes for any trip length for the particular airplane being considered, and also the percentage of schedule time reduction possible for the 25,000ft. cruising over the 10,000ft. operation which may be realised approximately in any airplane operating under similar conditions.

If these data are interpreted in terms of a typical trans-continental airline schedule, it may be expected that this airplane, cruising at 25,000ft., will be able to make the trip without stopping in about 80 min. (9.5 per cent.) less time than the same airplane flying at 10,000ft. with the same power. If the airplane stops once during the trans-continental flight, it may be expected to save 74 min. (9 per cent.) by cruising at the higher altitude. If it stops three times, it may be expected to save 52 min. (6 per cent.). If stops are made once every 300 miles, there is practically no advantage in going to 25,000ft. for cruising.

This indicates that the practical advantage in time saved by cruising at a high altitude is not large except for very long flights such as are necessary in trans-oceanic service. In the latter operations, the time saved is not particularly

important except in regard to its effect on the amount of fuel which must be carried. For any specific flight length, the fuel load reduction credited to the time saved must be corrected for the higher specific fuel consumption necessitated by supercharging for the higher-altitude operation, and for other weight penalties mentioned later. For operation over land, the time saved in making long flights at high altitudes is not ordinarily of as great importance as the advantages of increased pay load obtainable by making an occasional stop for fuel.

If restrictions on the rate of descent imposed by passenger comfort and safety are eliminated (as by use of a supercharged cabin), a slight additional time saving may be accomplished by cruising at high altitudes, but this does not materially alter the data as presented.

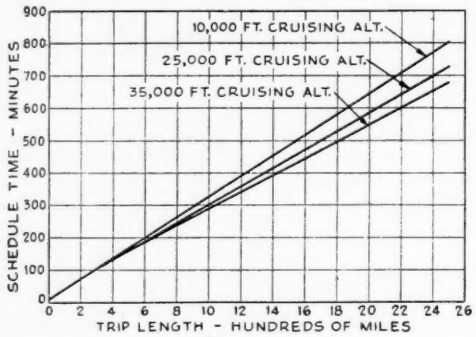

FIG. 4.

Schedule Performance of a Typical Transport Airplane.

(The station-to-station time includes (1) 10 min. manœuvring time, (2) time to climb to cruising altitude with 110 per cent. cruising power, (3) time at cruising altitude with cruising-power rating, and (4) time gliding from cruising altitude with cruising-power rating.)

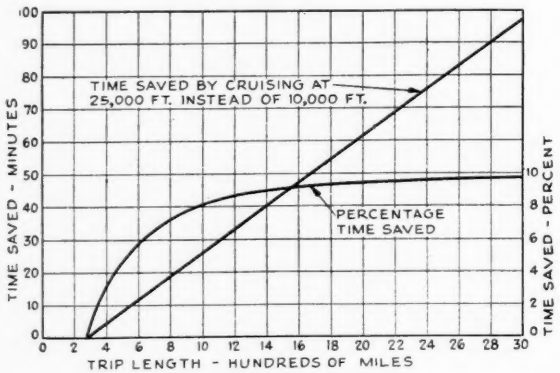
TIME SAVED BY CRUISING AT 25,000 FT. INSTEAD OF 10,000 FT.
PERCENTAGE TIME SAVED
TIME SAVED - MINUTES
TIME SAVED - PERCENT
TRIP LENGTH - HUNDREDS OF MILES

FIG. 5.

Schedule Time Saving Resulting from Cruising at High Altitude.

Pressure Cabin Required for Passengers

Since experience has indicated that passengers cannot ordinarily be carried at altitudes higher than 12,000 or 14,000ft. without increasing the air pressure in the cabin above that of the surrounding atmosphere, the fuselage must be substantially airtight for high-altitude cruising. This is not impractical, though

it involves some increase in structural weight. In order to minimise difficulties, it would seem advisable to maintain the cabin pressure at about 10lb. per sq. in. abs. at altitudes above 10,000ft., at which altitude that atmospheric pressure is the normal value. If this procedure is followed, the internal pressure which the cabin must withstand will be nearly 7lb. per sq. in. abs. at 35,000ft. altitude. The stiffness required of the normal fuselage is such that the conventional structure will, in general, be adequate for the bursting loads. The principal structural changes needed will occur at bulkheads and doors.

A troublesome problem is encountered in arrangements for maintaining the cabin pressure and in providing for ventilation. The power needed by a centrifugal compressor to raise the pressure from atmospheric to 10lb. per sq. in. abs. is shown in Fig. 6, for the range of flow ordinarily considered acceptable in ventilation practice. Assuming that a value of about 20 cu. ft. per min. per passenger is satisfactory, the power required will be about 2 h.p. per passenger at 35,000ft. The utilisation of the main power plant to supply this energy is immediately suggested for economy of both structural weight and fuel. In the case where a two-stage supercharger is used for the engine, the first stage might possibly supply the cabin pressure and ventilation with the assistance of pressure- and volume-control apparatus. A small auxiliary compressor driven by an exhaust gas turbine would be both economical of fuel and flexible in operation.

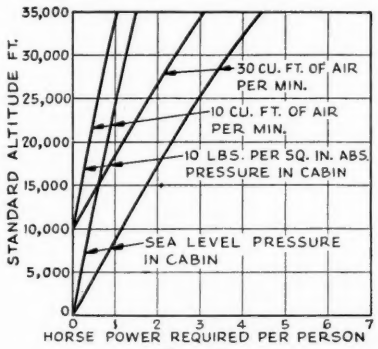

FIG. 6.

Horse-power Required per Passenger for Supercharging Cabin.

In addition to the desired cabin pressure and ventilation, a large portion of the heat required for the comfort of the passengers would be supplied by the same centrifugal compressor. While this amount of heat would have to be supplemented by an exhaust-heated steam boiler or other appropriate means, the heated air supply would furnish a large part of the requirement except at low altitudes. Under unusual atmospheric conditions, cooling of the cabin air supply might even prove necessary as indicated by the temperature data of Fig. 7. The high-temperature air must be carefully distributed in the cabin to avoid uncomfortable hot spots.

Automatic devices are required to control the cabin pressure and temperature, and a spare cabin supercharger may be necessary to protect the safety of passengers in case of a mechanical failure. If it is desired to employ high rates of descent to save time, it will be necessary to insure a gradual change of pressure within the cabin. This may be accomplished by temporarily raising the absolute pressure in the cabin above 10lb. per sq. in. abs. just prior to landing, or by decreasing the rate of descent at low altitudes. The continual use of sea level pressure in the cabin involves both additional structural weight changes and an

increased power consumption. The number of devices required for cabin supercharging and pressure control again emphasises that an airplane intended for cruising at high altitudes must be a relatively large unit in order to achieve a reasonable pay load capacity.

Difficulty with boiling of the fuel at low pressure will be aggravated at higher altitudes and it will probably be necessary to apply cabin pressure to the

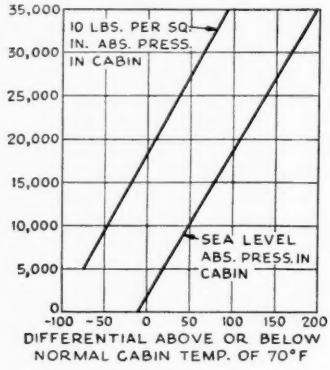

FIG. 7.

Temperature of Air Discharged from Cabin Supercharger.

fuel system. This matter and numerous similar detail problems will need careful attention if successful operation is to be achieved. The precision of navigation instruments, for example, is a matter of increasing importance as speeds and distances are increased. However, it is believed that the solution of any of these problems does not present major difficulties.

Conclusion

The preceding discussion leads to the conclusion that the additional complications in structure and auxiliary apparatus required for high-altitude cruising with passengers probably does not warrant that type of flight operation except in the case of long non-stop flights over water, or to avoid or make use of weather conditions on the flight route. However, the latter item may be a very important consideration when it is desired to take advantage of prevailing winds. If these special considerations induce the construction of a highly specialised, pressure-cabin type of airplane for high-altitude operation, the flight path normally used (neglecting winds) should be at the maximum altitude permitted by the degree of supercharging of the power plant. It seems probable that the supercharging methods available for service use in the near future will not provide for the maintenance of the cruising-power rating at altitudes greater than about 25,000ft., and that the fuel consumption of such an engine will be materially higher than that of a similar engine supercharged for operation at relatively low altitudes. This increased fuel consumption, plus the additional penalties resulting from the necessity for a supercharged cabin, severely restricts the commercial utilisation of the increase in airplane speed achieved by flight at high altitudes.

ABSTRACTS OF PATENT SPECIFICATIONS

(*Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.*)

Abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

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Aerodynamics

438,991. *Improvements in or relating to Means for Reducing the Resistance to Motion of Material Bodies.* Huet, A., 27, Rue de Longchamp, Paris, France. Convention date (France), December 19th, 1933.

The inventor states that he has discovered that when deflectors of normal type are used to reduce the resistance of bodies in air, swirls, eddies and friction are caused and also a vacuum behind the deflectors so that the reduction of resistance aimed at is not obtained. In order to obviate this the inventor has discovered that it is not enough to admit fluid behind the deflectors, but that this fluid must have a certain direction and velocity. Drawings are given of bodies having suitable deflectors of various forms intended to carry out the proposed principle.

Aeroplanes—Construction

439,954. *Improvements in Aeroplane Wings.* A.T.S. Co., Ltd., 3/4, Clement's Inn, Strand, London, W.C.2, and Lloyd, J., Whitley Aerodrome, Coventry, Warwickshire. Dated June 13th, 1934. No. 17,516.

This specification describes a metal box spar for aircraft in which the spar is formed of corrugated top and bottom members and two side webs, the spar being shaped to the camber of the wing and covered with fabric or the like. Transverse members are fitted which support the top and bottom members of the spar. The corrugations may have flat sides, tops and bottoms and the webs may also be corrugated.

439,645. *Improvements in and relating to Windshield Devices for Cockpits of Aircraft or for Equivalent Spaces in other Vehicles.* Petters, Ltd., and Davenport, A., Westland Aircraft Works, Yeovil, Somerset. Dated June 27th, 1934. No. 19,028.

This windscreen has a transparent roof which is capable of being slid backwards and there is also a door on each side for the access and egress of the pilot. The upper part of the door contains radial movable panels arranged as in a fan

so that when these are opened the pilot can put his head outside for vision in foggy weather. The roof is supported in cantilever fashion over the space occupied by the doors, so that when all are open the pilot has a free exit.

437,177. *Device for Absorbing Torque in Spring Cantilever Struts on Flying Machines.* Vereinigte Deusche Metallwerke Aktiengesellschaft Zweigniederlassung Heddernheimer Kupperwerk, Heddernheim, Frankfort-on-Main, Germany. Convention date (Germany), July 2nd, 1934.

In order to transmit the torque which may occur between the movable and fixed portions of a single leg chassis from the wheel axis to the fixed portion, it is proposed to use a system of links hinged respectively to each other and to the fixed strut and to the fixed axes, the whole arrangement resembling roughly a lazy tongs drive with a single link system. The links are formed with a central oval-shaped hole through which passes the movable strut of the chassis.

Aeroplanes—Control

437,447. *Improvements in Aeroplanes.* Buheiji Fugimoto, No. 63, Chomes, Kagura-cho, Ushigoma-ku, Tokyo, Japan. Convention date (Japan), May 23rd, 1933.

It is proposed to make the inner portions of the wing of, say, a monoplane movable about an axis located approximately about the front spar position. This movable portion has flaps and carries an engine so that by manipulating the flaps it may be rotated into a vertical position. The outer portion of the wing is of normal form and is supported by the member on which the inner portion rotates. It is stated that this arrangement facilitates landing.

439,592. *Improvements relating to Controlling Arrangements for Aeroplanes.* Messerschmitt, W., Hannstetterstrasse 118a, Augsburg, Germany. Convention dates (Germany), February 24th, 1934, March 14th, 1934, and March 24th, 1934.

This specification is concerned with the use of spoiler vanes as a means of lateral control for aircraft. The vane is placed on the upper surface of the wing, and is hinged on its forward edge so that raising the vane spoils the airflow over the wing. It is stated that at angles of incidence of less than 10° the spoiler vane has little effect on the control until it is raised to a larger angle and methods are described by means of which this disadvantage may be overcome. For this purpose the vanes may be constructed in sections, being raised one after the other, or the vane may be flexible, one end being moved more than another.

Aeroplanes—General

439,365. *Improvements in Aircraft.* Downing, A. E., 35, Clive Street, West Bromwich. Dated June 13th, 1934. No. 17,484.

This invention is intended to make flying safer and easier to accomplish, which can, it is stated, be effected by economy of power, high thermal efficiency combined with silence, light loading, great capacity for gliding, ability to fly slowly, automatic stability and absence of risk from fire. The machine proposed has a long car body with a series of laterally extending fixed or adjustable gliding wings, and a series of wings which are reciprocated for propulsion. The propulsive and lifting power is applied with great power to a series of movable wings so that in their propulsive thrust they leave behind a series of isolated vortices rather than produce columns of wasted energy with voids to fill up with furious winds.

439,963. *Improvements in or relating to Aircraft.* McLaughlin, R. J., 73, West End Avenue, Manhattan Beach, Brooklyn, New York, U.S.A. Dated June 18th, 1934. No. 17,985.

The aeroplane shown in the drawings is approximately of the normal form of a high wing monoplane, but the rear part of the fuselage is provided with a passage into which air enters from underneath the front of the fuselage and the air is discharged in an orifice at the tail. In this passage way there is a cylindrical rotor, rotated by the air passing through and operating two Magnus rotors placed externally of the fuselage. In the passage way there are, in addition, three smaller cylindrical rotors which, it is stated, produce a lift, Instead of the external Magnus rotor an arrangement of rollers carrying a canvas cover, so arranged that when exposed to air currents the canvas takes a form approximating to an aerofoil, may be used. A Magnus effect may be obtained by revolving the rollers and moving the cover in the appropriate direction.

441,074. *Improvements in or relating to Aircraft.* Bishop, W. H., 48, Moor Street, Birmingham. Dated July 12th, 1934. No. 20,450.

In order to prevent stalling of the wings of aircraft it is proposed to provide an opening in the upper part of the wing in the position where it is stated that the pressure of the boundary layer falls below a safe minimum. This opening is provided by raising the upper surface of the wing up to this point, thereby leaving a gap between this raised portion and the normal wing. The backward edge of this raised surface is turned inwards and there may be a backwardly curved member fitted below it so as to prevent flow of air into the opening from the upper portion of the wing. An opening or openings are provided on the compression side of the wings and/or fuselage in order to feed the opening with air.

441,084. *A New and Improved Windscreen for Aircraft.* Vickers (Aviation), Ltd., and Wallis, B. N., Weybridge Works, Byfleet Road, Weybridge. Dated July 13th, 1934, No. 20,575, and March 23rd, 1935, No. 9,141.

This windscreen is primarily intended for use as a gun mounting in which protection is given to the gunner and is intended to be mounted either in the front or rear of an aeroplane fuselage. It is circular in section so as to form a faired continuation of the fuselage, is constructed mainly of transparent material and is fitted with a slot on one side in which moves the gun mounting. The whole mounting can be rotated while the gun can be rotated in its mounting, or the mounting may be moved along the slot enabling in this way the whole of the possible gun arc to be covered. Sliding covers are provided for closing part of the slot, brakes are provided for holding the gear in any required position; counterbalance weights are provided and are moved so as to automatically balance the weight of the gun. Provision is also made for balancing wind loads on the gun. The gunner's seat is adjustable and is attached to the fuselage proper.

Autogiros

438,525. *Improvements in and relating to Aircraft with Rotative Wings.* Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2, and Bennett, J. A. J., Genista, Newton Mearns, Renfrewshire, Scotland.

This specification refers to the type of autogiro rotor in which the rotor may be revolved by the engine at a speed greater than that used in flight, the rotary blades being at a reduced angle of incidence. On cutting out the engine and simultaneously increasing the blade incidence angle the machine may be caused to jump off the ground, the energy for this action being provided by the excess rotary energy of the rotor. Each rotor blade is provided with three articulations, one in the flapping plane, another in the drag plane, and a third inclined

outwards. The purpose of this last is to come into action when a torque is applied to the hub and to reduce by its movement the angle of incidence of the blades. When the torque vanishes, as by declutching the motor, the blades take up their normal flying incidence. The movement is limited by stops where necessary and arrangements are made so that the bearing of the third articulation has a greater friction than the second.

438,660. *Improvements in and relating to Blades for Aircraft Sustaining Rotors.* Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2, and Bennett, J. A. J., Genista, Newton Mearns, Renfrewshire, Scotland. Dated May 16th, 1934. No. 14,816.

This specification refers to a proposed method of construction of the blade of an autogiro. The main structural member consists of a metal tube running the length of the blade. The tube has a section the top of which is that of the upper front surface of an aerofoil, the lower portion having the same section inverted and reversed. The aerofoil section is completed by means of wood fairing, say, of balsa and spruce, the latter wood being used where strength is necessary. The main tube may be reinforced by other approximately oval tubes sprung into place, and details of the method of attachment of the hub connections are described.

Bombs and Ballistics

440,156. *Improvements in or relating to Means for Carrying Bombs on Aircraft.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex; Youngerman, R. T., Walcot, Church Crookham, Aldershot, Hants; and Holroyd, F., Old Hatch Manor, Ruislip, Middlesex. Dated May 8th, 1935. No. 13,567.

In order to enable bombs to be stored within the fuselage of an aeroplane and to be released, if desired, outside the propeller disc, and also to facilitate loading, it is proposed to provide a runway transversely to the fuselage and situated in the wing so that a bomb to be released may be carried along the wing away from the fuselage and there released. Such a runway could be used in the reverse direction to facilitate loading, bombs being placed on the runway and carried into the fuselage. The opening in the wing caused by the runway is closed by a roller blind device.

441,350. *Gun Mountings for Aircraft.* Mare Birkigt, Rue du Capitaine Guynemer, Bois-Colombes (Seine), France. Convention date (Belgium), Nov. 20th, 1934.

This specification refers mainly to guns buried in the wings of aircraft so that only the muzzle projects from the leading edge. The chase of the gun is connected to the front spar, preferably through springs, so as to prevent abnormal loads affecting the spar, while the rear of the gun is attached to the rear spar in a manner which prevents the spars being stressed when the gun lengthens when hot. References are made to specifications 414,300 and 441,349.

438,717. *Improvements relating to the Mounting and/or Control of Machine Guns, Camera Guns, their Sights and the Like.* Stieger, H. J., General Aircraft, Ltd., Croydon Aerodrome, Croydon, Surrey. Dated June 14th, 1933. No. 16,999.

It is proposed to mount a machine gun or guns in an aeroplane in a position slightly distant from the gunner. For instance, the rear gunner may sit within the fuselage and the gun may be positioned above his head. In order to manipulate the gun the gunner has a separate sighting device attached to the gun and his seat, so that on rotating the seat the gun traverses for elevating. The

gun is connected to the sight by a chain gear or link gear so that the gun follows the elevation or depression of the sight. Arrangements are described from one or two guns, for various positions of the gunner in the aeroplane, and for means for automatically preventing the gunner from hitting portions of the aeroplane.

Control of Aircraft

436,680. *Improvements relating to Brake Controls for Aircraft.* Miles, F. G., and Powis, C. O., Reading Aerodrome, Woodley, Reading. Dated July 18th, 1934. No. 21,048.

It is proposed to operate Bowden wire brake controls by means of a plate carried under the rudder bar, which plate carries two levers adapted to come in contact with the rudder bar. These levers operate the brakes on each side of the machine. Variable braking is arranged for by means of another manually-operated Bowden cable which moves the plate carrying the levers in a fore and aft direction. When the plate is farthest from the rudder bar each brake can go on only when the rudder bar is moved to an extreme position; when the plate is moved near to the rudder bar both brakes may be on, but there is still differential action when the rudder bar is moved.

436,579. *Improvements relating to Automatic Course Control Devices for Aircraft, Marine Vessels, or Vehicles.* Siemens and Halske Aktien Gesellschaft, Berlin-Siemenstadt, Germany. Dated January 8th, 1934. No. 686. The application for a patent has become void.

This specification refers to automatic course control devices and describes a means whereby deviations from the direct course, caused by wind, etc., may be compensated for. This is achieved by a supplementary adjustment of the said automatic course steering device corresponding to the angle of duration determined from the desired course, for example, by taking a bearing by means of a wireless direction finding frame or by means of a telescope, the angle between the actual course and the desired course being ascertained in this way. Since the angle of deflection is known to the pilot, the latter can influence the steering of the craft accordingly or can supervise the operation of the steering on the indicating apparatus of an automatic steering device.

441,102. *Improvements in and relating to Control Surfaces for Aircraft.* Short Bros. (Rochester and Bedford), Ltd., and Gouge, A., both of Seaplane Works, Rochester, Kent. Dated November 17th, 1934. No. 33,126.

In the case of aircraft fitted with balanced control surfaces, such as ailerons, in which the balance is provided by hinging the surface at some position behind the leading edge, it is stated that considerable air resistance is caused normally by the gaps necessitated by the brackets which carry these hinges. It is proposed, therefore, to carry these hinges by a shallow member, such as a tube, projecting from the plane and working in a slot in the leading edge of the aileron. Provision is made for cover piece to be readily detachable so as to enable the hinges to be easily accessible.

441,103. *Improvements connected with Slots for Aircraft.* Blackburn Aeroplane and Motor Co., Ltd., Seaplane Base, Brough, and Bumpas, F. A., Elloughton, Brough, Hull, East Yorks. Dated December 27th, 1934. No. 37,059.

In the case of aircraft wings fitted with slots it is stated that it is desirable that the slots should be locked while the machine is on the ground in order to prevent wind damage. This specification describes a method by which the slots may be manually locked while the machine is standing and also automatically unlocked when the machine is operated, as, for instance, by the pilot operating

the ailerons. The apparatus described is a bell crank lever, provided with a lock to engage with a member attached to the slot, and maintained in either the locked or unlocked position by a spring device.

440,659. *Air Circulating Valve in the Supporting Surfaces of Aeroplanes.* Mazzini, F., Via Andrea Doria 42, Milan, Italy. Convention dates (Italy), July 5th, 1933; March 10th, 1934.

In order to increase the resistance of aircraft wings while landing so as to facilitate this operation and possibly also to increase lift, it is proposed to provide a slot shaped passage from the lower to the upper side of the wing capable of being closed by a valve. This passage runs along the span of the wing and its location in the chord direction may be in any position found desirable. The valve may be of the plug type with either parallel or tapered passage, or may be of a hinged type so formed as to give when open a passage of any desired shape. In certain cases the valve may be automatically operated.

Engines

438,384. *Emergency Fittings for Aircraft.* Horsbrugh, A. M., 12, Renfield Street, Glasgow, C.2. Dated July 3rd, 1934. No. 19,550.

For the purpose of rapidly emptying the fuel tanks of aircraft in emergency, the fuel tank is provided with a large emptying valve which is cross-connected to a valve connecting with a compressed gas reservoir so that both valves open together. The escaping gas enters the fuel tank driving out the fuel.

435,879. *Flexible Mountings for Aircraft Power Units.* Armstrong-Siddeley Motors, Ltd., Wylie, H. N., and Gay, A. R. B., all of Armstrong-Siddeley Works, Park Side, Coventry, Warwickshire. Dated May 22nd, 1934. No. 15,241.

The flexible mounting proposed includes an annular support and a radial flange on the engine having parts which spigotally engage one another through resilient means. Thus, to take the main portion of the weight of the engine attachment, bolts carried by the support or by the flange and extending through the latter with clearance and resilient means located on the support and on the flange to absorb the engine torque reaction chiefly in shear, the compression of this latter resilient means being variable by adjustment of the bolts.

440,656. *Apparatus for Handling Engines.* Vickers (Aviation), Ltd., Glen, W. A., Rayner, F. W., all of Weybridge Works, Byfleet Road, Weybridge Surrey. Dated July 3rd, 1934. No. 19,575.

This appliance consists of a tube bent into a quadrant of a circle, one end of which carries a further tube projecting inwards at right angles to which is hooked the engine crankcase, the other end of the quadrant being attached to the engine propeller shaft. On the tube there runs a sheave pulley to which is attached a strap which engages with a crane hook or other lifting device. The radius of the quadrant may be struck from the C.G. of the engine so that it is easy to place the engine in any desired position.

Helicopters

437,521. *Improvements in and relating to Aircraft.* Wilkening, F. W., Arlington and Braeburne Roads, Penn Valley, Montgomery County, Pennsylvania, U.S.A. Convention date (U.S.A.), February 2nd, 1934.

This specification describes a lifting rotor designed both to be power driven and also to autorotate, suitable medium angles for the two phases being obtained automatically and the motor being arranged close to the hub of the rotor. Each

blade is carried by a short link hinged at each end so that it is free vertically and horizontally. When power is applied the blades swing back owing to the torque and this action is utilised to increase their angle of incidence through a bevel gear, one member of which is carried by the link. The angle of incidence is stated to increase with an increase of torque and when power is cut off the blades swing forward and take up automatically a blade angle suitable for autorotation.

437,715. *Improvements in and relating to Aircraft.* Wilkening, F. W., Arlington and Braeburne Roads, Penn Valley, Montgomery County, Pennsylvania, U.S.A. Convention date (U.S.A.), February 2nd, 1934.

This specification describes an aircraft intended to be lifted by power driven rotary propellers acting vertically. The fuselage carries in front and rear vertical surfaces which can be placed at an angle to counteract torque, and there is also a tail plane or elevator which is used to tilt the whole machine so that propulsion can be obtained from a forward component of the lift force. The tail plane also carries ailerons and vertical surfaces.

436,981. *Improvements relating to Devices for Damping the Oscillation of the Revolving Wings or Blades of Aircraft.* Kay Gyroplane, Ltd., Kay, D., and Dyer, J. W., 18, Atholl Crescent, Edinburgh, Scotland. Dated June 26th, 1934. No. 18,889.

In the case of rotors with blades hinged on the two planes, it is stated that when movement is allowed in the plane of the blades rapid oscillations have been found to occur. It is therefore proposed to arrange in the wing a weight capable of movement in the chord direction which act by their inertia so as to oppose the rebound of the blade. Damping devices may, in addition, be fitted to the hub of the rotor.

437,034. *Improvements in and relating to Helicopter and Rotating Wing Aircraft.* Coats, A. G., Gloucester House, Park Lane, London, W.1, and Hafner, R., Mantlergasse 47, Vienna, 13, Austria. Dated April 23rd, 1934. No. 12,214.

This specification refers to the blades of lifting rotors and is concerned particularly with blades which are connected to the central hub by means of torsionally flexible radial members which take centrifugal forces in tension. In order to prevent the blade flying off if the tension member breaks, each blade is fitted with a collar which would come in contact with a member screwed into the hub, if breakage took place. Normally, there is clearance between these members.

441,445 *Improvements in or relating to Aircraft.* Mangold, S., 13, Gonzagagasse, Vienna 1, Austria. Dated July 5th, 1935. No. 19,312.

The proposed aircraft is provided with three or more lifting or propelling airscrews located at the apices of a polygon and arranged to be driven from the engine through a differential gear or gears. Steering can be effected by braking the propelling airscrews on one side of the aeroplane, while lateral control can be obtained by braking the lifting airscrews in the same manner.

439,298. *Improvements in Helicopter Flying Machines.* Porter, J. R., Whatley Road, Clifton, Bristol.

This invention comprises a horizontal lifting screw rotating in one direction and a second lifting propeller rotating in the opposite direction, the second lifting propeller consisting of a power-driven lifting propeller having radial arms at the end of which circular rings are attached, these rings being set at an angle with the vertical axis of the machine, the section of the lifting rings being of aerofoil

shape. The rings, during rotation, cut the air and drive it downwards, thereby producing an upward lift.

435,818. *Improvements in or relating to Helicopter and Rotating Wing Aircraft.* Coats, A. G., Gloucester House, Park Lane, London, W.1, and Hafner, R., Mantlergasse 47, Vienna 13, Austria. Dated March 29th, 1934. No. 9,867.

In the case of rotary wing aircraft it is stated to be desirable that the axes of the hinges of all blades should intersect. In order to enable this to be done with three blades, each blade is provided with an unsymmetrical fork, the longer leg of which lays outside the shorter leg of the adjacent fork. The hinge pins of the latter work in clearance holes in the longer legs of the forks. The blades are provided with means for altering their inclination by means of radius rods operated by a spider carried by a central control column.

440,476. *Improvements in and relating to Aircraft.* Wilkening, F. W., Arlington and Braeburn Roads, Penn Valley, Montgomery, Pennsylvania, U.S.A. Convention date (U.S.A.), February 2nd, 1934.

The machine proposed is a helicopter provided preferably with a device by which the lifting rotor may autorotate when the motor stops. As there is only one rotor, this, when engine driven, would cause a rotative force on the fuselage; this force is opposed by two or more surfaces disposed symmetrically with reference to the rotor axis and in the rotor slipstream and so inclined as to counteract this torque. These surfaces may have ailerons for control purposes and may also be used as radiators for cooling the motor.

Miscellaneous

439,038. *Improvements in or relating to Liquid Containers.* Dornier Metallbauten, G.M.B.H., Friedrichshafen, Lake Constance, Germany. Convention date (Germany), June 19th, 1933.

In order to make light tanks tight against leakage it is proposed to cover them internally with a porous fabric attached by means of an adhesive liquid proofing medium, the joints being covered by a metal bar riveted to the tank. The bar itself is covered by a further application of the fabric and medium. Alternative methods of applying the fabric are described.

439,240. *Improvements in and relating to Aircraft.* Holler, H. P., Town of Poplars, Maryland, U.S.A. Dated April 30th, 1934. No. 13,000.

The arrangement described consists of a combination between a dirigible balloon and an aeroplane. The balloon is elliptical in section and has underneath it a cabin fuselage which possesses wings with downwardly folding tips which are locked in the horizontal position in flight. Underneath and round the aerostat runs the narrow platform of the main bridge with railings and electrically-driven lifting propellers may be used.

439,284. *Method of and Means for Preventing the Accumulation of Ice on Aircraft.* Barker, G. G., 14-18, High Holborn, London, W.C.1. Dated April 3rd, 1934. No. 10,016. (A communication from Bendix Aviation Corp., 105, West Adams Street, Chicago, U.S.A.)

It is proposed to utilise for this purpose a system of appropriately located flexible and expansible overshoes, which are expanded and contracted in such a way that the ice formation is broken up before it becomes dangerous. The overshoes are alternatively inflated and deflated in such a manner that the exhaust of one shoe or a group of shoes is used for the inflation of other shoes. The air for inflation is supplied by an engine-driven pump and a slow speed distributor.

Model Aircraft

439,826. *Improvements in or connected with Toy Aeroplane Gliders.* Back, W. E., Oulton Broad, Suffolk. Dated June 16th, 1934. No. 17,880.

This specification describes a toy glider on which the angle of incidence of the wing on either side of the body is adjustable, in which the wing is mounted pivotally and controlled by rubber in which rubber is incorporated in the leading edge of the wing and on which the angle of the tail plane can be altered so that the glider can loop the loop.

Ornithopters

422,667. *Ornithopter.* Karl Haenle, 99, Finkenkrugerwey, Berlin-Staaken, Germany. Dated May 28th, 1934. No. 15,806.

Instead of making the wing ribs of an ornithopter flexible so as to get the required flapping action it is proposed to use stiff and indeformable wings capable of rotation round the spar and controlled by springs. The tension of the springs may be altered by turning the spar in order to give control. This control gear consists of a lever mounted on the wing spar operated by a screwed spindle.

Rocket Propulsion

439,805. *Improvements in Jet Propulsion Apparatus for Aircraft, Projectiles and Turbine Apparatus.* René Laduc, 3, Avenue Gabriel Dupont, Le Vesinet-Seine-et-Oise, France. Convention dates (France), June 7th, 1933, and January 2nd, 1934.

This specification describes a jet propulsion apparatus which has variously shaped passages in which the temperature and velocity of the fluid may be varied in accordance with a cycle. The nozzle comprises a compression zone, a source of heat, an expansion zone, a source of cold and a compression zone.

Seaplanes

437,465. *Improvements in or relating to Wing Tip Floats for Seaplanes.* Short, H. O., and Gouge, A., Seaplane Works, Rochester. Dated June 28th, 1934. No. 19,101.

It is proposed to utilise the wing tip floats of a seaplane for the purpose of damping any oscillation which may occur in the wings. In order to do this the floats are attached to the wings by means of inverted wing struts and wire bracing and also by a diagonal member containing springs and a damping mechanism. As the period of oscillation of the wings and float are different, any oscillation of the former would cause the floats to endeavour to move in a different period which would bring the damping mechanism into action. The diagonal spring member may also absorb landing shocks.

Testing

440,198. *Apparatus for Testing the Resistance of Structural Parts, Particularly Parts of Aeroplanes.* Bugatti, J., Molsheim, Bas-Rhin, France. Convention dates (France), March 12th, 1934, and April 25th, 1934.

In order to approximate to flight conditions when testing aircraft structurally it is proposed to use a device consisting of a platform larger than the span of the machine, two columns at each end of the platform connected at their upper ends by a girder and two forked members capable of motion on the columns arranged to support air or water bags in contact with the wings. These bags may be inflated to any desired pressure and the load may be applied through them or through a down or up load applied to the fuselage. Tests may be made with engine running or other methods of producing vibration may be used.

Undercarriages

440,358. *Improvements relating to Retractable Undercarriages for Aircraft.* Hawker Aircraft, Ltd., Canbury Park Road, Kingston-on-Thames, Surrey; Duncan Davies, S., and Down, C. R., of the same address. Dated June 27th, 1934.

This chassis is stated to be particularly suitable for low wing monoplanes and is characterised by a device which enables the wheel to be swung inwards and backwards when retracting so as to clear the wing spar. Each wheel has its own chassis, this consisting, when extended, of one approximately vertical member carrying the shock absorbing device, one member leading upwards and backwards and a third member leading upwards and inwards. The member going backwards has in its length a link at its upper end which is straight when the chassis is extended. On turning a tube, which can be rotated hydraulically, this link is moved out of line, and in doing so draws the chassis backwards. At the same time the rotating of this tube turns the whole chassis inwards so that it folds into a recess provided.

438,770. *Improvements in and relating to Aeroplane Undercarriages.* Elektron-metall, G.M.B.M., Camstatl, Germany. Convention date (Germany), June 29th, 1934.

It is proposed to construct an aeroplane chassis by providing, for each wheel, a single supporting member which carries at its lower end a link projecting backwards. The other end of this link carries the wheel and the shock absorbing device is enclosed in a member starting from the wheel axis, the other end of which is attached to the single supporting member at some distance above its lower end. The link is connected rigidly to the brake plate for the purpose of taking braking loads.

441,432. *Improvements in or relating to Undercarriages for Aircraft.* G. and J. Weir, Ltd., Holm Foundry, Cathcart, Glasgow, and Pullen, C. G., 104, Queen's Drive, Glasgow, S.2. Dated January 21st, 1935, No. 1,906, and September 27th, 1935, No. 26,719.

The chassis referred to is stated to be particularly suitable for aircraft of the autogiro type and consists of a stub axle for each wheel connected to the fuselage by three struts, two in front elevation leading from the stub axle and connected to the fuselage one above the other, and one in side elevation proceeding from the stub axle upwards and backwards to the fuselage. All are fitted with shock absorbers, but the strut proceeding backwards and upwards has shock absorbers adapted to function only in tension.

REVIEWS

Handbuch der Meteorologischen Instrumente

Edited by E. Kleinschmidt. Springer, Berlin, W.9. Price 69 R.M.

No less than a dozen scientists collaborate in this handbook, in which the subject of meteorological instruments is dealt with in true German thoroughness. The instruments are described under the following headings:—(1) Temperature, (2) Sun Radiation, (3) Humidity, (4) Dust and Rain, (5) Pressure, (6 and 7) Wind Velocity, (8) Atmospheric Electricity, (9) Optical and Acoustical Phenomena. Although the book deals mainly with apparatus commonly employed in meteorological stations, the reader will find complete accounts of modern aeronautical instruments under their appropriate headings. Apart from these, the sections on pilot balloons and kites will interest members of the Society, the hundred or so pages devoted to the latter aerostat forming a compendium of information on large kite flying, which, so far as the writer is aware, is not readily available elsewhere.

Turbulenz

By H. Gebelein. Springer, Berlin, W.9. Price 12.5 R.M.

This book deals with the latest views on turbulent motion, particularly the statistical view. It is the fashion nowadays to regard the Newtonian formulation of mechanics as being an expression of large-scale events and mere generalisations of the laws of small-scale mechanics, sufficient for every-day use owing to our " long sightedness." The more that we become endowed with " microscopic eyes " through the development of delicate physical apparatus, the more do we become aware of an apparent indeterminacy in material motions. This causeless Lilliput was first observed in the electron realm, but now the disease of indeterminacy is attacking hydrodynamics, and the molecular motions of matter such as are involved in the propagation of sound.

The work under review, besides describing the statistical view of turbulence in great detail, contains a useful general account of the theories of probability and the correlation of events. It is perhaps unfortunate that the bibliography is rather scanty, and that as such is almost entirely confined to work done in the author's fatherland. This is a criticism all the more noteworthy in that the reviewer has to apply it more often to books emanating from this country than from those of Germany. The reader anxious to obtain the latest news on turbulence will certainly need to supplement an otherwise useful volume with some account of the work, both theoretical and practical, done in English-speaking countries.

Machine Drawing for Students

F. J. Price, B.Sc. Published by Sir Isaac Pitman and Sons, Ltd. Price 7/6.

This book belongs to the Aeronautical Engineering Series of Messrs. Pitman and should be a useful text-book for students. It is concerned with the actual drawing and dimensioning operations carried out on the drawing board, and the author's views on how these things should be done are usually sound. It is generally found that every different drawing office has its own methods, and

although these may not be quite the best, have the important advantage of being thoroughly understood by the shops which work to them.

The book would be improved if more space was devoted to instruments. The student requires some help in selecting suitable types and is sometimes liable to waste money in buying expensive instruments which are unnecessary. There is also a rather involved error in the bottom of the first column of page 4, where feet and inches seem to have become interchanged in a confusing manner. But the book generally should fulfil its purpose of assisting the engineering student in learning mechanical drawing and should save him much trouble when he eventually reaches the drawing office.

How to Build Flying Boat Hulls and Seaplane Floats

By J. Streeter. Published by Sir Isaac Pitman and Sons, Ltd. Price 6/-.

This book is a new addition to Messrs. Pitman's Aeronautical Engineering Series. Considering its small bulk, Mr. Streeter contrives to give a very considerable amount of information about the methods of construction of metal hulls and floats, dealing with the whole process from setting out to the testing of the complete hull. There is also a useful chapter on methods of repair.

The book can be recommended as an excellent treatise on its subject, which is one likely to come into much greater importance in the immediate future.

CORRESPONDENCE

AERONAUTICAL RESEARCH COMMITTEE

4th March, 1936.
Teddington, Middlesex,
National Physical Laboratory,

The Secretary,
The Royal Aeronautical Society,
7, Albemarle Street, London, W.1.

Dear Sir,—Herr O. Schrenk has drawn attention to the use in England of the term Schrenk flaps to denote flaps projecting normal to the under surface of the wing section. He points out that his original work was carried out conjointly with Herr Gruschwitz and that similar work has been done independently in other countries. He does not, therefore, wish his name to be associated with this form of flap. The Aeronautical Research Committee propose in future to refer to such flaps as " split flaps."

Yours faithfully,
J. L. NAYLER, *Secretary*.

The 601st Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

A meeting of the Royal Aeronautical Society was held in the lecture theatre of the Institution of Electrical Engineers, at Savoy Place, Victoria Embankment, London, W.C.2, on Monday, January 6th, 1936, at which Mr. J. E. Hodgson, Hon.F.R.A.E.S., lectured on "Sir George Cayley," and surveyed his long and varied experimental work in connection with the science of aeronautics.

In the chair, Mr. C. R. Fairey (Past-President of the Society).

The Chairman reminded the members that on Sunday, January 12th, 1936, the Society would attain the age of 70 years. It had enjoyed an unbroken existence since 1866, and was by far the oldest aeronautical institution in the world. Seventy years was regarded as man's normal span of life, and in man it was a very critical age. The Society, however, as its activities proved, needed no Voronoff to rejuvenate it.

It was unfortunate that the Society's 70th anniversary should fall on a Sunday, so that it could not be celebrated by the delivery of Mr. Hodgson's lecture on that day.

There was not time, in the course of a few introductory remarks, to remind the members of even a thousandth part of the activities of the Society during the 70 years of its life. But more than 600 papers had been read before the Society by all the great authorities on aeronautics in the world; such names as James Glaisher, Horatio Phillips, Hiram Maxim and Lord Rayleigh, among many others, occurred to one as the names of eminent members. And one noted with pleasure that one of the Society's "youngest" members, Major Baden-Powell, who had been a member for 57 years, was present at the meeting; he was a Past-President of the Society.

One of the important functions of a Society such as ours was the custodianship of aeronautical history; it was a duty of the Society to find out and to place on record the true facts of aeronautical history, in order that the pioneer might be given the credit due to him and to ensure that it was not filched from him by the crank or the charlatan. There were within its ranks many of the greatest pioneers of aeronautical science. The story of possibly the greatest of the pioneers, Sir George Cayley, was to be told by Mr. Hodgson, a very eminent lecturer, the leading authority on the history of aeronautics. Many had read his work on that subject. But there was another reason why the members of the Royal Aeronautical Society owed him a debt of gratitude. For more than seven years he had been the Society's Honorary Librarian; the Society owed gratitude to him for its fine collection and fine cataloguing of that collection, and many rare volumes and manuscripts which it would otherwise have missed had been brought to its attention by his indefatigable efforts. He had studied the subject of Sir George Cayley's work with great zeal, and had studied the very manuscripts and drawings which Sir George had left behind him.

Mr. Hodgson: Before delivering his lecture, he would like to express his appreciation of the presence of Major Baden-Powell, who had been a most ardent supporter of the Society, particularly in the days when it had had to struggle, when the number of members had dwindled to a handful and he had had to approach various people almost with hat in hand to beg for money with which

to pay the rent. Owing to the tremendous pace with which events had moved since that time one was perhaps rather apt to forget those pioneers who had done such valuable work in the early days of the Society's existence.

SIR GEORGE CAYLEY
THE FOUNDER OF BRITISH AERONAUTICAL SCIENCE

BY

J. E. HODGSON, Hon. Fellow

It is, I suppose, known to most of those present in this lecture hall that the Royal Aeronautical Society was founded in 1866—to be exact the first preliminary meeting was held, under the chairmanship of the Duke of Argyll, on January 12th, though the first meeting of members did not take place until the 27th of June following. It is, therefore, within a few days of 70 years ago that the Society came into being. That is a full and honourable age, and with it goes the distinction—in which we are entitled to take some pride—of being the oldest Aeronautical Society in the world. The anniversary may not arouse the enthusiasm usually associated with the more youthful glamour of a silver or a diamond jubilee. On the other hand it denotes another decade of progress in the growth of aeronautical science, and of even more marked developments in the application of that science, on which grounds alone it deserves passing notice.

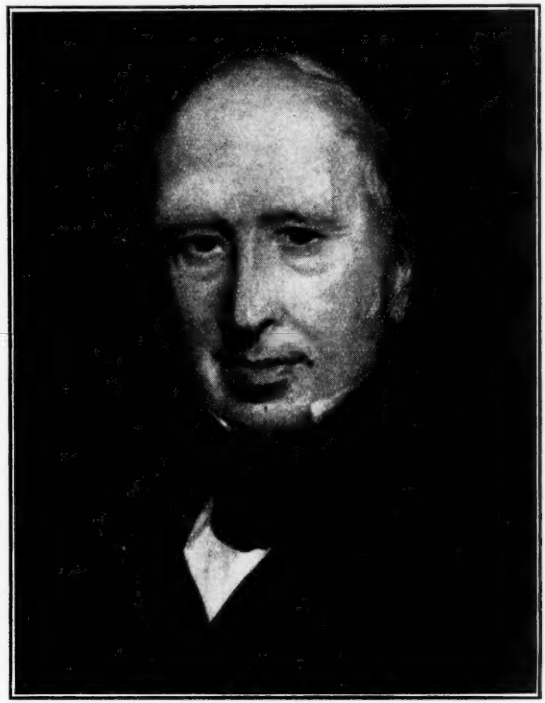
It was, I gather, for some such reasons your Council felt that as an unpretentious way of celebrating this 70th birthday of the Society, it might depart once from the direct purpose for which it was formed, namely " to foster and develop the science of aeronautics," and more fittingly substitute for this occasion a paper dealing with some historical aspect of the past. I fully realise that to those working in the full flood of present-day problems and practice, matters historical are apt to be disregarded as of no practical interest or value. That, I would venture to suggest, is not a wise view—on the contrary we cannot afford to ignore the lessons that history and the experience of the past teaches. Moreover, to disregard them is to lose the inspiration and encouragement which comes from a knowledge, however slight, of the problems and difficulties which beset the great pioneers of the past, and the manner in which they overcame them.

Be that as it may, the decision as to a historical lecture having been taken, there remained only the question of subject. That question was left open, and I take all responsibility for the ultimate choice, namely " Sir George Cayley as the Founder of Modern Aeronautical Science." The choice was not easy, for there are many aspects of the history of aeronautics, as of any other great science. It might, for instance, have seemed proper to deal with the history of this Society, whose work and influence has unquestionably been of the highest importance.[1] I believe, however, that the Society's work, both through its many distinguished individual members, past and present, and as a body, is adequately, if not fully, known. On the other hand, I do not think the work of Cayley as the founder of aeronautical science and the father of the aeroplane, is, even yet, sufficiently appreciated.

Moreover there was a further consideration. For some time past I have had in my care, thanks to Sir Kenelm Cayley, all the papers on aeronautical, mechanical, and scientific matters which have survived since Cayley's death in 1857. These papers—which I shall refer to as the " Cayley papers "—include

[1] See " The Royal Aeronautical Society: A Survey, 1866–1929," by the present author. Air Annual of the British Empire for 1929.

the " Aeronautical and Miscellaneous Note-Book " (*ca.* 1799-1826), which has been printed by the Newcomen Society,[2] and which, though not as well known in this country as its interest deserves, was the subject of a discerning and appreciative article by M. Pierre Léglise in " L'Aéronautique " for March, 1935. Beside this there are a considerable number of odd notes and memoranda in Cayley's own hand—mostly draft calculations and measurements, rough sketches of flying machines, and so forth—as well as something like 200 letters, all concerned with aeronautical matters, in some cases with copies of Cayley's replies, dating between 1809 and 1850. As will be seen later, certain of these letters



Portrait of Sir George Cayley, by Briggs, at Brompton Hall, near Scarborough.

are of special interest as written to original members of this Society. Finally, there is a long " Communication " sent by Cayley in 1853 to the " Société Aérostatique et Météorologique de France," consisting of five pages folio, in double columns, with several pages of drawings, only the first part of which was published in the French Society's Bulletin. (No. 4, 1853.)

As to the manuscript notes and correspondence, none of which has been published, though they afford many interesting quotations and throw light on the details of Cayley's ideas and endeavours, I do not pretend that they afford any new material of importance. Of this I am certain—that the Cayley papers

[2] Newcomen Society for the Study of the History of Engineering and Technology, Extra Publications, No. 3, Heffer & Sons, Ltd., Cambridge, 1933.

as a whole are of the greatest interest, and as such should certainly be preserved in some suitable public institution.

Coming to the substance of my paper, I have divided it into three parts: First, a brief account of Cayley's life; second, a chronological précis (so to speak) of the extant knowledge of his aeronautical endeavours, whether in the form of manuscript notes, printed essays or letters, and private correspondence; and third, a summary of his contributions to aeronautical science, in both departments of aerostation and aviation, *i.e.*, heavier and lighter-than-air flight.

First, as to his life. George Cayley was born at Scarborough on December 27th, 1773, and educated first for a short time at York, and then at Nottingham, in the latter place under the tutorship of Rev. George Walker (1734-1807),[3] a mathematician of some note in his day. At the age of nineteen he was sent to Southgate to study under George Cadogan Morgan (1754-1798),[4] a scientist of high repute and the author of works on electricity and chemistry. As a boy, Cayley showed an early interest in mechanics—he is said to have "spent every spare moment with the village watchmaker," and he himself records that it was in 1792 that he made his first experiment in aeronautics with a so-called Chinese flying top. On the death of his father, Sir Thomas Cayley, in 1792, Cayley succeeded to the baronetcy, and three years later he married Sarah Walker, the only daughter of his former tutor, by whom he had a family of ten children.

Though the management of a large area of agricultural land forming part of, or contiguous to, the family estate at Brompton (about seven miles from Scarborough), and his interest in local affairs, to say nothing of the upbringing of his children, must have occupied him largely in early manhood, nevertheless Cayley found time to devote himself to scientific and engineering concerns. Besides his major work in aeronautics, on the air-engine, and his invention of the tension wheel—both of which were primarily designed for aeronautical uses—he was the inventor of the caterpillar tractor, or Patent Universal Railway, as he termed it.[5] He was also interested in automatic signalling and other apparatus for the purpose of preventing accidents on railways; in a new type of self-righting life-boat; in experiments with rifled shot; in the design of a clever piece of mechanism for use as an artificial hand, and other projects. On the scientific side he was interested in general physics, in optics more particularly, and in electro-magnetism. Of knowledge at large he had the reputation of being a "perfect walking dictionary on all subjects."

Though Cayley lived for a time in London and elsewhere, and made several journeys abroad—during which he became acquainted with Arago, Baron de Ferussac and other French scientists—he spent the greater part of his life at Brompton Hall. There he built a workshop—still standing—in which he carried out many experiments in furtherance of his aims in aeronautics.

As a life-long supporter of Parliamentary Reform, he was elected Member for Scarborough, in the Whig interest, in the first Reform Parliament of January, 1833, but he retired before the next election two years later. He seldom took part in the debates, and probably his longest speech was a reasoned appeal in support of Sir Goldsworthy Gurney's petition for the alteration of tolls on steam-carriages upon common roads. He died at Brompton Hall on December 15th, 1857, and was buried beneath the chancel in the neighbouring church.

Second, as to the chronological record of his work. I have adopted this form because it brings out more fully and clearly in a cumulative sense than has been attempted heretofore, Cayley's life-long enthusiasm and pertinacity in the cause of "aerial navigation"—a term he himself introduced as "giving a little more dignity to a subject rather bordering upon the ludicrous in public estimation." For it will be noticed that his first experiment was made in 1792—

[3] Dictionary of National Biography, Vol. 59, 1899, p. 58.
[4] *Op. cit.*, Vol. 39, 1894, p. 15.
[5] Cayley took out a patent for his "Revolving Railroad" in 1825, No 5260.

at the age of 18—and his last reference to the subject in writing is dated 1855—at the age of 83, or two years before his death.

It has been stated that Cayley's interest in flight was awakened by the invention of the balloon by the Montgolfier brothers in 1783, but he does not himself refer to it. It is more certain that the first idea he " ever had on the subject of mechanical flight was at Southgate about the year 1792."[6] The experiment, if such it can be called, consisted in making a helicopter toy of feathers, corks, a shaft of wood, and a bow of whalebone, which when wound up and released would " fly up to the ceiling of a room." It is generally assumed that Cayley got this idea from a project invented by two Frenchmen, Launoy and Bienvenu, the one a naturalist and the other a mechanic, who gave a demonstration of their model helicopter before members of the French Academy in 1784.[7] Doubtless the assumption is correct, though as Cayley does not mention the original inventors, it is probable he only learned of it through some indirect source.[8]

Though this experiment with the Chinese flying top was simple in the extreme, it had great significance for Cayley as affording " a very beautiful specimen of the action of the screw propeller in air," and as being " capable of the most powerful and extensive application." In other words, he was convinced at this early date of the practicability of using the " air-screw " as soon as a prime mover could be found to drive it.

During the next few years Cayley must have devoted a great deal of thought to the problem of flight, though no written evidence remains. An interesting souvenir, as it may be termed, has, however, recently been acquired by the Science Museum which helps to mark the progress of Cayley's ideas and affords a representation of what would appear to be his first design of a flying machine. It consists of a silver disc about one inch in diameter, and dated 1799, which bears a crude design—in the same style as those found in the Note-book—of a man-carrying machine with a fixed curved wing or plane above a boat-shaped car. Extending from the rear of the car are two large oars or paddles, while the tail unit is a structure forming horizontal and vertical rudders, the earliest idea of which has been associated with the drawing of the 1804 " glider " in the Note-book. Beneath are the initials " G.C.," which make it certain that the design and workmanship are Cayley's own. On the reverse is a diagram of the forces relative to the machine on the other side.

If the date on this disc is correct—and there is no reason to doubt it—Cayley's ideas on design had outstripped, as he must have known well enough, his experimental work. This is confirmed by entries in the Note-book, for during the next few years, that is from 1800 onwards, he carried further his theoretical examination of bird flight, as revealed by the frequent notes on the flight of many types of birds—notes which were based on careful observations and measurements, and from which he deduced reasonably sound conclusions, mainly in the direction of the ratio of weight to wing surface. It must not be overlooked, however, that he worked before the days when much greater knowledge and accuracy were made available by the photography of movement.

But observations of bird flight, interesting and even inspiring though they are in relation to flight at large, could not greatly help in the solution of the problems of mechanical flight. A much more important and significant step was taken by Cayley on December 1st, 1804, when he commenced the series of experiments—the first of the kind ever made for purely aerodynamic purposes—

[6] The quotation is from a letter to R. B. Taylor, written by Cayley in 1842. But in his article published in Nicholson's Journal, Vol. 24, 1809, the date is given as 1796.

[7] See Lecornu, J. La Navigation Aérienne, Paris, 1903, p. 95.

[8] In his Contribution to the Bulletin of the Soc. A. et M. de France in 1853, Cayley referred to the flying top merely as sold some years ago " for the amusement of children in London, and probably in Paris."

with a primitive form of whirling-arm. These interesting experiments are best described in Cayley's own words. " I made the following experiments," he writes in the Note-book, " upon the resistance of air to a surface a foot sq., carried round with an horizontal motion upon an arm suspended upon a delicate hinge. The length of the arm from the pivot to the centre of resistance was 4 feet 9.2 inches. This arm played up and down upon an hinge fixed into the part that was carried round by the upright pivot, and counterpoised by a weight on the other side of the hinge, so that the $\frac{1}{16}$ of an oz. turned it easily from an horizontal position. The whole was braced by a cord over an upright in a part of the frame to give firmness to the structure. . . . The motion was communicated by a cord going over a pulley and then down a stair case, with a bag to hold weights at pleasure. The angles which the plane made with the horizon were measured by a plummet quadrant, and the weights lifted upon the path of the plane by a pair of common scales. The number of revolutions carefully noted with a stop watch. The centre of resistance was computed by squaring the velocities that each vertical stripe of the square one foot wide gave, and finding the medium point of resistance. I first selected a velocity of about 21 feet $\frac{1}{2}$ (21.82 feet) per second, conceiving that this gave one pound pressure upon a foot surface when perpendicular to the motion. . . . Hence I weighted the machine so as to make 8 revolutions in 11 seconds. The weights supported under this velocity were as follows."

He then gives readings at increasing angles of incidence from 3 to 18 per cent.—another feature of these experiments here tried for the first time—and the weights supported. Subsequently he varied the experiments and therefrom drew general conclusions. But having " doubts, however, whether this mode of circular motion does create as much resistance as when the plane moves on in a right line keeping parallel to itself "—doubts which were justified for more than one reason—he constructed what unquestionably appears to have been his first model " glider " or " aeroplane." He describes this likewise primitive machine as follows: " A common paper kite containing 154 sqr. inches was fastened to a rod of wood at the hinder end and supported from the fore part from the same rod by a peg, so as to make an angle of 6°. With it this rod proceeded on behind the kite and supported a tail, made of two planes crossing each other at right angles, containing 20 inches each. This tail could be set to any angle with the stick. The ratio about 5 sqr. feet of surface to the pound." " It was very pretty," he adds, " to see it sail down a steep hill and it gave the idea that a larger instrument would be a better and a safer conveyance down the Alps than even a sure-footed mule, let him meditate his track ever so intensely. The least inclination of the tail towards the right or left made it shape its course like a ship by the rudder."

It is not possible to enter on any discussion of the data these experiments provided, let alone as to their accuracy, which obviously could be no more than comparative and approximate. In this connection it may be desirable to comment briefly on Cayley's mathematics. As already mentioned, his first tutor was a mathematician of some note, but Cayley's mathematical methods, judged by modern standards, were very elementary, even though they were adequate for his purpose and used with general accuracy. But if their simple character suggests some lack in his mental equipment as a scientific experimentalist, the well-known fact that the English school of mathematics was for long isolated by its devotion to geometrical methods must not be overlooked. It was not until 1803 that Robert Woodhouse, the first to explain the notation and methods of the calculus as used on the Continent, published his " Principles of Analytical Calculation," and some years elapsed before such methods were generally adopted.[9] In any case, it is fair to say that the experiments justified Cayley's growing convictions, which had already found expression in his first, but un-

[9] Ball, W. W. R., " Short History of Mathematics," 1912, p. 438.

finished " Essay upon the Mechanical Principles of Aerial Navigation." In that essay, dated October, 1804, Cayley expressed the view that although " the long wished for art of flying with wings can never be attained," modern mechanics had provided in the steam engine, and other first movers, an incentive to further researches on the principle of the inclined plane—a principle " subject to strict mathematical investigation," and proved to be true by many experiments made during the previous eight or nine years.

This question of a sufficiently powerful first mover within the weight required—" the *sine qua non* in the case," as Cayley said—was indeed destined to prove a snare and a delusion; a snare because it occupied so much of his time and money during the next 30 or 40 years; a delusion because the hot-air or caloric engine of which he was the inventor and on which he expended so much mechanical ingenuity proved at long last an impracticable failure. It is, however, significant of Cayley's early faith in mechanical flight, that his first printed paper " which had reference to the subject of aerial navigation," was the article published in 1807 on an " Expansion Air Engine." This engine, which was first constructed for him at Newcastle some years earlier by William Chapman, consisted of two double-acting cylinders in tandem, the larger being the working cylinder and the smaller a pump which forced air through the fire contained in a separate airtight furnace, thereby heating it, the hot air being then admitted alternately to the ends of the working cylinder and expanded down to the atmospheric pressure when it is exhausted. Mechanical difficulties resulting from the high temperature involved prevented its successful development, and later attempts in the same direction proved abortive owing to the weight and bulk for the power generated being so great as compared with an internal combustion engine. It is of greater interest to note that a suggestion made by Cayley in connection with the hot-air engine, viz., that it might be found desirable to obtain more heat by the injection of " inflammable gas, oil of tar, or other inflammable matters," led to the pregnant consideration that a " much cheaper engine of this sort might be produced by a gas-light apparatus and by firing the inflammable air generated with a due proportion of common air under a piston "—a remarkable adumbration of the internal combustion engine and an idea which he might well have striven to develop more profitably than his pet air engine.[10]

A minor attempt to produce a prime mover on a principle akin to the hot-air engine was made by Cayley in 1807, when he constructed, " for some preparatory experiments," a small engine in which " the force of gunpowder and the heat evolved by its explosion, acting upon a quantity of common air, was employed." He also used gunpowder for generating heat in " a very odd sort of boiler," though he admitted in a letter to Lord Campbell in 1820 that, while he had met with no accident, he " never liked to venture near the boiler when turning the engine "—or, as he put it when commenting in 1843 on the danger of gunpowder for such purposes, " who would take the double risk of breaking their necks or being blown to atoms." But it was doubtless because Cayley had experienced the difficulties involved in the matter of available power that during 1808 he fell back on the construction of experimental flying machines having fixed surfaces or sails, some of which were designed to be propelled by flapping wings actuated with a man's arms. It was probably about this time he made the large " vehicles "—as he termed them—" having 3 to 4 hundred feet of canvas extended on masts and braced by rigging to give strength and precision of position to their surfaces." One of these—broken, as Cayley tells, before the propelling apparatus could be tried—weighed 56lb., and was loaded with 84lb., or 2 sq. ft. to a lb., and when launched from a hill sailed downwards with stability and steadiness according to the set of the rudder. Frequent references by Cayley in both printed articles and correspondence, show that he

[10] Cayley took out a patent for his air engine in 1837 (No. 7351, Improvements in the Apparatus for Propelling Carriages [and] other purposes).

made numerous experiments of this kind; for instance, in a letter to Lord Mahon (afterwards Earl Stanhope), written in 1809, he writes: " I have seen weights of as high as 10 stone, including the engine [that is the machine] itself, hover in the air with perfect steadiness." Doubtless the difficulties of launching these large machines led to the idea of using wheels, with the result that in the same year Cayley invented the tension or bicycle wheel as " being the lightest possible wheel for aerial navigation cars "—a very remarkable invention, and one which was almost universally adopted when the aeroplane became an accomplished fact nearly 100 years later.

During 1808 there followed further, and conceivably more fruitful experiments with a simpler form of " glider "—practically a large kite, of hexagonal form, with curved surfaces and horizontal and vertical rudders—which Cayley used for the earliest known investigations on the problem of the centre of pressure. In the year following he was concerned with the more abstruse problem of the solid of least resistance, the great importance of which he realised, though he admits that he found the subject " of so dark a nature as to be more usefully investigated by experiment than by reasoning."

Having by this time accumulated a considerable body of data and experience, he incorporated the whole in contributions to Nicholson's " Journal of Natural Philosophy " during 1809 and 1810.[11] These articles form his most important printed contributions to the science of mechanical flight. They were reprinted in the Annual Report of this Society for 1876, and again in 1910 as No. 1 of Aeronautical Classics. For this reason they are the main, and frequently the only known source of knowledge about Cayley's work, and as they are still readily available it is not necessary to deal with them here. Though it is not likely they were widely read at the time, these articles brought him into touch with men interested in the subject. One of these was Sir Anthony Carlisle, a distinguished surgeon, who for some years had been interested in flight—though he dared not admit it in public—and from whom Cayley may have got a suggestion as to the suitability of bamboo canes in the construction of flying machines. Another was Earl Stanhope, through whom he sought to obtain information as to the machine used by Degen, a watchmaker of Vienna, who had made futile attempts to fly suspended beneath a balloon—though the latter fact was discreetly evaded in most accounts. In one of his replies, Cayley lays stress—as he often did on other occasions—on the great importance of a " long course of experiments on a large scale, conducted under the eye of a person accustomed to the mathematical application of mechanics," and made a tentative suggestion as to forming a committee of those interested in such matters.

The years 1800 to 1810 had thus been mainly occupied with mechanical flight—and the air engine. But perhaps owing to the fact that no progress was made with the latter, Cayley turned his attention to navigable balloons, and during 1816—1817 he contributed three letters on the subject to Tilloch's " Philosophical Magazine."[12] In these he discussed some of the main principles on which the airship is based, in particular the necessity of great dimensions. In this connection he compared the 100-gun ship of about 270ft. in length with the dimensions he conceived would be necessary in " the long boat of aerial navigation, which commences about the bulk where the man-of-war of common navigation has reached its full growth." This basic factor in airship theory he re-stated more clearly in 1837 in the simple terms that " the surfaces (and hence the resistances) increase as the squares of the diameter of the balloon, whereas the capacity to contain gas (and hence the supporting power) increases as the cubic of the diameter." " We must be contented," he wrote, " to give up balloons for purposes of locomotives altogether, or to attempt them on that scale

[11] Nicholson's Journal of Natural Philosophy, Vol. 24, 1809, p. 164, and Vol. 25, 1810, pp. 81 and 161.
[12] Tilloch's Philosophical Magazine, Vol. 47, 1816, pp. 81 and 321, and Vol. 50, 1817, p. 27.

of magnitude which a well-grounded calculative of their power proves to be necessary." He also discussed the question of shape; methods of inflation—hydrogen or hot air; the need for internal air pressure and stiffening with light poles and cross bracing; the desirability of dividing the oiled-silk gas containers into several sections; the cloth—" made impervious to rain," for the outer envelope, and the danger from fire and methods of preventing it.

It was at this time that Cayley made his first suggestion as to the formation of a society to conduct experiments with navigable balloons—a suggestion based on the fact that the great size and consequent expense which he knew to be necessary were beyond the powers of individual resources. Though he received some offers of support, the suggestion fell through. Possibly the only practical result was that it brought Cayley into touch with Lord Campbell, and they undertook during the next year or two some joint experiments with a model balloon, 28ft. long,[13] which conformed approximately in shape with the " very oblong spheroid " (" but varied according to what may be found the true solid of least resistance "), as laid down by Cayley in his first essay of 1804. Perhaps the lack of support discouraged him at the time, for as far as is known he did little in aeronautics between about 1825 and 1836. On the other hand, it may well be that what he regarded as his political duties fully occupied his time, and it has been already mentioned that he was Member of Parliament for Scarborough during 1833-34, which involved his living in London.

But on his retirement and return to Brompton Hall his enthusiasm revived, and in 1837 he contributed to the " Mechanics' Magazine " an article entitled " Practical Remarks on Aerial Navigation " which was concerned almost entirely with navigable balloons, his faith in which, as " offering greater facilities for transporting men and goods through the air, than mechanical means alone, inasmuch as the whole weight is suspended in the air without effort," is forcibly restated.[14] Though he modified his suggested design on the very large dimensions described in his earlier article, and though he admitted that such dimensions were " much in advance of the present experimental state of the subject," he made new suggestions as to the possibility of using coal gas as to separate tubes to the gas compartments to maintain pressure, and to the fact that as the power of navigable balloons to break away from moorings would decrease in the same ratio as in passing through the air, " they would keep aloft and be firm and steady in their position under anchorage, even in a storm."

In 1840 Cayley renewed his efforts to achieve by public subscription what was beyond his own efforts or purse, and with that object in view he suggested the formation of a " Royal Aerostatic Institution." A first meeting was held at the Polytechnic Institution—of which Cayley was one of the founders—and though nothing came of it, the attempt is of special interest to this Society by reason of the people Cayley approached. One of these was the Duke of Argyll—an ardent supporter of the French " heavier-than-air " school—who afterwards became the first President of the Aeronautical Society. Another was Sir William Fairbairn, a distinguished engineer, who became one of the first Members of Council, while others included Robert Hollond and Charles Green, the former an original member, the other an occasional supporter of the free balloon—against the gibes of the President and those members who regarded it with unnecessary contempt—in discussions at early meetings of the Society.

In 1843, on the publication of the premature but none the less most remarkable design for a monoplane by W. S. Henson, Cayley contributed two further articles to the " Mechanics' Magazine,"[15] in which he pointed out some of the difficulties he foresaw in the construction of the so-called " Ariel Steam

[13] Amongst the Cayley Papers is a bill for £40, being the cost of materials and making, but there is no record of results.
[14] Mechanics' Magazine, Vol. 26, 1837, p. 417.
[15] Mechanics' Magazine, Vol. 38, 1843, pp. 263 and 273.

Carriage." Three years later Henson wrote to Cayley, to whom he referred as the " Father of Aerial Navigation," and sought financial support in further experiments. In a copy of his reply—which is amongst the Cayley papers—Cayley suggested that Henson's " Ariel " project, though true in principle, had been " rushed upon with far too great confidence as to its practice." The letter concluded with the pregnant and prophetic words, " a hundred necks have to be broken before all the causes of accident can be ascertained and guarded against."

Cayley's last and not least remarkable contribution to mechanical flight was the article which, at the request of Dupuis Delcourt, he contributed—as already mentioned—to the Bulletin of the French Aeronautical Society in 1853. In the first part—which alone was published owing to the cessation of the Bulletin—he urged the need for further experiments on the principle of the inclined plane, to be made by the use of " wing waftage," in order to obtain a " sound practical basis for calculating the engine power necessary." At the same time he refers to the advantages of the screw propeller in respect " of its uniform, direct, horizontal pressure," and with the question of light motive power still in mind, suggests that experiments with an engine using hydrogen or carburetted hydrogen gas as fuel, would appear to be the most promising. The second part of the article is mainly a description of the accompanying designs for an experimental flying machine, but there are also a few interesting references to Cayley's own experiments—from numerous memoranda, mostly undated, among the Cayley papers, there can be no doubt he was occupied with the construction and trials of " gliding " machines as late as 1850 to 1853—for instance, when he relates how " a boy of about ten years was floated off the ground for several yards on descending a hill." The essay concludes with an appeal to the Society to " occupy itself, under a scientific committee, with *experimental results*, rather than theoretical discussions."

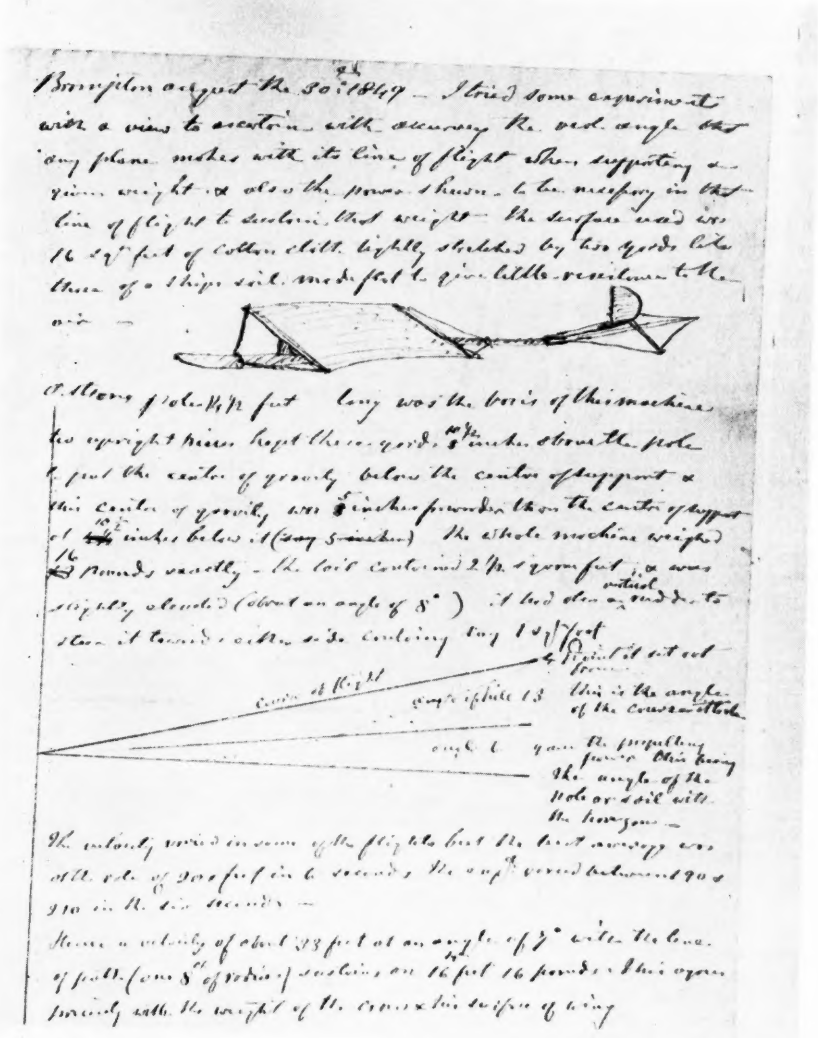
Actually and strangely enough, Cayley's last extant writing on flight, was a " Description of an Improved Flying Top "—as sent to Dupuis Delcourt in 1855—with the primitive form of which he had first experimented over 60 years earlier. Thus the wheel has come full circle—and two years later he died. If it be said, and the question may naturally be asked, " How much nearer was Cayley to the achievement of flight after more than 50 years of endeavour?" The answer may best be made in the statement that that record of endeavour, equally in the cause of flight whether by mechanical means or by navigable balloons, is unequalled—at least as far as my knowledge goes—in the history of aeronautics, at that or any other period of time, and in this or any other country.

Lastly, to summarise as briefly as possibly Cayley's contributions to both branches of aeronautical science. Before doing so it is desirable, for the sake of historical perspective, to prefix a few remarks as to the respective positions at the time when Cayley first took up the subject.

As to mechanical flight the position is easily explained. From the days of Roger Bacon—the first man of learning to refer to the subject on mechanical lines—in the 13th century, down to the end of the 18th century, the ideas on, and the endeavours to achieve flight, had practically all been based on the flight of birds. It is true that in the early years of the 16th century Leonardo da Vinci not only made experiments on the mechanics of flight, but also wrote a treatise of the greatest interest on the " Flight of Birds." In these he went far beyond anything that had been done before. As shown by Mr. Ivor Hart in his admirable and comprehensive study of the " Mechanical Investigations of Leonardo da Vinci," he propounded, discussed, and elucidated the many problems involved in a masterly scientific spirit.[16] Nevertheless, for Leonardo, as

[16] Hart, Ivor B., " The Mechanical Investigations of Leonardo da Vinci," 1925, Chapters VII and VIII.

for the countless would-be, minor pioneers of succeeding centuries, the ultimate aim was flight to be achieved on the ornithopter or flapping-wing principle. Such exceptions as there are—for instance, Leonardo's idea of the helicopter—do not affect the general truth of that statement.



But with Cayley there begins a new era, with its inception of the principles of the inclined plane—in a word the birth of the aeroplane. Though, as we have seen, he was eager to learn the secrets of bird-flight, and though—in the absence

of any other method—he contemplated the use of flapping wings as " possibly the first means of ascertaining the basis " of flight, Cayley laid it down for the first time that " the whole problem is confined within these limits, viz. :—To make a surface support a given weight by the application of power to the resistance of the air." His experiments, both in the workshop and the field—" the minutiæ of which," he wrote to Lord Campbell, " would require a volume to explain "—were directed towards the practical solution of that problem, or rather the many problems involved. It cannot be said that he solved any of them—with the scant available knowledge and inadequate apparatus, that was impossible. But he led the way in his endeavours to obtain data on resistances or pressures; he learned that a wing of concave section " resists much more than a plane surface "; he investigated what he significantly termed the " dark problems " involved in " stream-line " theory, and in connection therewith he laid it down that " every pound of direct resistance that is done away with, will support 30lb. of additional weight without any additional power." He was the first to investigate the problem of the centre of pressure, though he was barely aware of the problem of aspect ratio. From his experiments he also realised that the dihedral angle was, as he stated it " the chief basis of stability in flying machines," while in practice he advocated diagonal bracing as " the great principle for producing strength without accumulating weight." In other practical ways he was a forerunner; he was the first to suggest bi-plane or tri-plane—" two-deckers " or " three-deckers," as he said; he was also the first to use (if not the first to invent) the bicycle wheel as necessary in taking off and landing; he tried experiments with gliders towed by a rope, and suggested that it might be desirable to prepare a suitable mound, with a slope of about 50ft. curving off to a descent of 1 in 4—methods adopted towards the end of the century by Lilienthal and Pilcher.

Turning to the development of the navigable balloon, up to, say, the first decade of the 19th century, it need only to be said that on the invention of the fire balloon by the Montgolfier brothers in 1783, there followed almost immediately a realisation of the fact that its usefulness would be very limited, unless—as Dr. Johnson adequately put it—" its course can be directed so that it should serve the purposes of communication." But though it is true that in 1783 the French engineer, J. B. M. Meusnier, drew up a remarkable memoir on the whole subject of dirigible balloons, accompanied by equally remarkable designs for a spheroidal balloon driven by large airscrews actuated by manual power, the practical attempts to construct a navigable balloon, either on the Continent or in England, were almost wholly futile. The obvious fact that in order to guide balloons they must be of a cylindrical or elongated shape was quickly grasped, but very little thought was given, and, so far as is known, no experiments were made as to methods of maintaining the shape or as to propulsion and the power required.

When in 1815, if not earlier, Cayley turned his mind to the subject of navigable balloons, he investigated the problems involved on the same scientific and mechanical lines that he had already applied to heavier-than-air flight. These investigations were necessarily theoretical, for though he did make simple laboratory experiments on problems that were common to navigable balloons and mechanical flight, the question of expense " placed the proper scale of experiments quite out of reach of any individual." Hence his repeated efforts to form a society to " rescue this noble invention," as he said, " from for ever remaining a gaudy bubble in the hands of exhibition mongers." As already mentioned, Cayley's ideas on the subject at large were recorded in his contribution to Tilloch's " Philosophical Magazine " and in the " Mechanics' Magazine," and perhaps, need not be further discussed. It must suffice to say that though daring in conception as to magnitude, Cayley's ideas were in the main sound, and show no signs of the loose thinking, the ignorance, and the assurance which are common to so many of the countless navigable balloon projects of last century.

A few words may be added as to Cayley's influence. The names of Henson and Stringfellow naturally suggest themselves in this connection, but while I think that both these pioneers of flight were indebted to Cayley, the matter is dealt with by Mr. M. J. B. Davy in his excellent monograph on the subject, and I need not discuss it here.[17] There can be no doubt that apart from his general reputation as an engineer and scientist, his published writings on aerial navigation made his name widely known among his contemporaries in that connection. They brought him into touch—as the Cayley papers testify—with scientists and engineers of repute, with mechanics and inventors of more lowly position, as well as with those inevitable cranks who, having discovered to their own unqualified satisfaction, some secret solution of the problem, only require financial aid to accomplish the whole thing for the good of mankind. Amongst all such he was a living force, ever ready to explain what he believed to be the true principles of the science and mechanics of flight, to discuss and encourage sound suggestions, or to point out the weakness in erroneous ones—always in calmly reasoned and measured terms, with no desire either to claim sole credit for his own ideas, or to disparage those of others. But the number of the faithful whom he sought to lead must have been very small, and after his death, bearing in mind the common opinion that flight of any kind was an impossible delusion and that those concerned with it were mere misguided enthusiasts, or worse, it is not surprising that his name and fame were largely forgotten. Until within recent years writers on aeronautics in this country seldom did as much as mention him, and if so, quite inadequately—Wenham[18] and other members of this Society may fittingly be quoted as exceptions—while his name is not to be found in the Dictionary of National Biography. In France his work was more fully appreciated and studied, as witnessed by the fact that Cayley was asked to contribute to the Bulletin of the French Society—as already mentioned—and that Alphonse Pénaud, a notable pioneer of heavier-than-air flight in the later half of the 19th century, admitted his indebtedness, while it has been left for an authoritative French writer, M. Charles Dollfus, to hail Cayley as the " true inventor of the aeroplane," and one of the greatest geniuses in the history of aviation.[19] To a lesser extent Cayley's work was known in America, though Octave Chanute in his valuable work on the " Progress in Flying Machines," 1894, only quotes from the articles in Nicholson's " Journal of Natural Philosophy," and the Wright brothers—Wilbur Wright refers to Cayley as in the same class with such men as Wenham, Pénaud, or Langley—doubtless only knew of Cayley through Chanute. In any case the spread of ideas is an elusive subject, and it is unwise to attempt any definite allocation of influence in the spheres of either theory or practice.

Such is the extant record of Cayley's known contributions to aeronautical science. There is no need to exaggerate the value or importance of his work—indeed, speaking in this hall, devoted to another great science, the science of electricity, one's sense of historical perspective, and the presence, so to say, of the great men who gaze down on us from these walls, serve to restrain any tendency to do so. No, Cayley was not, for instance, a Faraday—he was not gifted with any comparable measure of that greater man's experimental genius, though he resembled him in nobility of character and an ardent desire to serve his fellow men. Nor, to turn to the mechanical side, was he a Trevithick—he lacked the full measure of that turbulent, prolific genius, which gives the great Cornishman a claim to be esteemed England's greatest engineer. Nevertheless, the basic inventive work of the three men as confined to their respective spheres

[17] Davy, M. J. B., " Henson and Stringfellow: Their Work in Aeronautics, 1840–68," Science Museum, 1931, p. 12.

[18] Wenham, F. H., " Aerial Locomotion," in the first Annual Report of the Aeronautical Society for 1866, p. 43.

[19] Dollfus, C., and H. Bouche, " Histoire de l'Aeronautique," Paris, 1932, p. 55.

of aeronautics, electro-magnetism, and locomotive engineering, does stand comparison. For though—as, indeed, Cayley foresaw—a longer time was destined to elapse before his " seeds of thought " came to fruition, Cayley's primitive experimental flying machine of 1804, stands in the same relation to the 40-seater air liner of to-day, as Faraday's equally primitive electro-magnetic apparatus of 1831—still, fortunately in possession of the Royal Institution—does to the stupendous modern developments in electric traction, or as Trevithick's model steam locomotives of 1796—made to run their trials, so it is said, on a kitchen table—to the huge and powerful railway locomotives used throughout the world to-day.

When, therefore, the time comes that the Royal Aeronautical Society, from being housed in two, or three, rooms in conditions quite beneath the dignity and the requirements of a great scientific and engineering body—and may I make bold to interject the remark, that had more past and present members of our Society cultivated some measure of that historical interest which draws inspiration from the achievements of pioneers, and strengthens imaginative faith in the progress of the future, the present inadequate, not to say deplorable state of affairs would long since have been a thing of the past—but when, I say, the time comes that we have a building of our own, with a lecture hall fit to be compared in elegance and equipment with that in which we now sit, with a well furnished library, and the rest, I trust care will be taken to give prominence to the name and fame of Sir George Cayley. Though I hold in the highest respect the distinguished and able men who, as Presidents, have guided with admirable zeal, enthusiasm, and success, the progress of our Society during the last 70 years, and whose portraits are ready to adorn the walls of our future house, not the less do I believe that it will be generally agreed the place of honour must be reserved for the great man who was at once the founder of modern aeronautical science as applied to mechanical flight, the inventor of the aeroplane, and a true pioneer of the great airship.

The CHAIRMAN: In proposing a hearty vote of thanks to Mr. Hodgson for his lecture, he said that one was very much impressed by the diligence with which he had investigated every scrap of evidence he had put forward. There was no controversy about the fact that Sir George Cayley was indeed the father of British aviation, and certainly he was a scientist and an Englishman whose memory the Society was proud to honour.

The Chairman was particularly interested in the references made in the lecture to the interchange of thought between the British and the French people on the subject of Sir George Cayley's work, because a few years ago he had had the honour of lecturing on British aeronautical history to the French Society and had shown some slides, which Mr. Hodgson had kindly lent him, relating to Sir George Cayley's work; he had been surprised to find that very few of those present on that occasion had believed that such a thing as a true aeroplane had been in existence in England 120 years before, or had given to Sir George Cayley's work the prominence due to it.

It was also very interesting to hear that Sir George Cayley was a pioneer in more than one direction, since he had had a hot air engine working in a brewhouse in the 18th century. Those who had visited " brewhouses " would observe that those hot air engines were still working.

A question which the Chairman asked was whether Sir George Cayley's glider had really flown. According to one story, he said, it had carried Sir George's coachman over a small valley; but the coachman was so unappreciative of the historical importance of the occasion that he had promptly resigned. It would be interesting to hear whether that was true.

The Chairman also commented upon the statement made during the lecture, to the effect that Sir George Cayley seemed barely to have been aware of the importance of aspect ratio. Certainly Sir George Cayley had invented the aero-

plane. He had spoken of the surface required to lift a given weight by the application of the pressure of the air; but from the records of his work, and his designs, it would appear that he was not aware, as Mr. Hodgson had said, of the importance of aspect ratio. Was there not something to be said on the technical side, therefore, for the work of Henson and Stringfellow, particularly when one had seen Mr. Hodgson's illustrations of the two machines? The Chairman would not dispute—indeed, he said, no one would dispute—Sir George Cayley's pre-eminence as an inventor and a scientist; but surely, on the technical side, Henson and Stringfellow deserved great credit for the fact that they did very obviously appreciate the importance of aspect ratio and many other features of the modern aeroplane.

Major B. F. S. Baden-Powell (*Past-President*): In seconding the vote of thanks to Mr. Hodgson, he said he would be unable to add much information to that contained in the lecture, one reason being, perhaps, that in the early days of aeronautics in this country the name of Sir George Cayley was hardly known. The name had been known by a few because he was the author of a paper or a magazine article; although that article was interesting, it was not regarded as of very great importance, and inasmuch as the issue of the magazine containing it was out of print and was difficult to acquire, very few people had read it. Only during recent years, chiefly through the efforts of Mr. Hodgson, had we been able to elicit very much information concerning Sir George Cayley's career and the wonderful amount of work he had devoted to the pioneering of aeronautics.

(The vote of thanks was enthusiastically accorded.)

Mr. Hodgson briefly expressed his appreciation, and again thanked Major Baden-Powell for having travelled to London in order to be present on this mildly auspicious occasion.

TEST REPORTS OF THE AERONAUTICAL LABORATORY OF THE R. ISTITUTO SUPERIORE DI INGEGNERIA OF TURIN*

2ND SERIES

CONTENTS

1.—Six-component balance with wire suspension (paras. 2, 3, 4; figs. 1 and 2).

2.—Open-jet wind tunnel of 600 mm. diameter, with return flow. Tests made for the purpose of determining the velocity distribution in a section of the jet with and without cascades at the bends, also with various shapes of collector cone and honeycomb (paras. 5, 6, 7, 8; figs. 3, 4, 5, 6).

3.—Electric tanks (para. 9).

4.—Tests on slotted wings with different shapes and positions of the slots, and with flaps of different forms and at different angles (para. 10; figs. 7 to 21: models from "Torino 22" to "Torino 21").

5.—Tests on aeroplane models (figs. 22 to 45; models "Torino 22" to "Torino 28").

6.—Tests on an undercarriage model with three different types of fairing (figs. 46, 47, 48; model "Torino 29").

7.—Tests intended to determine the interference effect of the airscrew on the horizontal tail surface of an aeroplane. Experimental determination and theoretical discussion of the aerodynamic characteristics of the airscrew. Experimental determination and theoretical check of the lift and rolling moment curves for three horizontal tail surfaces with different plan form, with advance/diameter ratios of the airscrew of 0, 0.1, 0.15, 0.20, 0.25, 0.30, for incidences comprised between 18 and +20 degrees, and for control angles of the elevator of 0 and 15 degrees (models "Torino 30, 31, 32"; figs. 49 to 68; airscrew model "Torino E1").

8.—Tests on models of motor cars. Drag, lift and moment curves (models "Torino 33, 34, 35"; figs. 68 to 74).

SUMMARY

The present 2nd Series of the "Rendiconti sperimentali del Laboratorio di Aeronautica del Reale Istituto Superiore di Ingegneria di Torino" follows on the 1st Series published in April, 1934. It includes:—

(1) Description of a new six-forces balance.

(2) Statement and discussion of the results of the tests on:—

(a) a 600 mm. wind tunnel with open jet and return flow, with the object of determining the influence on the steadiness and distribution of velocity of the stream in a cross-section of the jet of various details of design (dimensions of the cells of the honeycomb, cascades, etc.) and the diffusion of the portion of the airstream undisturbed by the air carried along by the jet owing to the effects of viscosity.

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* The text of the present report is the work of Professor Ferrari, holder of the Chair of Aerodynamics at the Turin Polytechnic and Member of the Administration of the Aeronautical Laboratory, which has forwarded the report.

It has been translated from the Italian by Miss V. M. Witty from "L'Aerotecnica," and is published by kind permission of Professor Panetti, Director of the Laboratorio di Aeronautica of the R. Istituto d'Ingegneria of Turin, and Professor E. Pistolesi, Editor of "L'Aerotecnica," in which Journal for November-December, 1935, the original paper was published.

(b) on fifteen models of wings.

(c) on three motor car models.

(d) on an airscrew model mounted at various lateral angles to the relative asymptotic wind (airscrew in a side wind).

(e) on three models of tail plane in the presence of an airscrew.

The last-mentioned tests on tail planes are part of a series of tests still being carried out with the financial assistance of the Directorate of Research and Experiments of the Air Ministry at the suggestion of General Crocco, with the object of determining the influence of the working airscrew on the aerodynamic characteristics of tail surfaces.

1. This Memorandum follows on the 1st Series of " Rendiconti Sperimentali " of the Turin Laboratory, published in *L'Aerotecnica* in 1934, and constitutes the 2nd Series of these reports. It contains the description of the most important new test equipment and plant added to the Laboratory since the first Report, and a statement of that part of the Laboratory's work which it is now permitted to publish.

Six-Forces Balance with Wire Suspension

2. The Laboratory is engaged on the development of a balance which by automatic means would enable the determination of the aerodynamic reactions on models of any shape and set at any angle to the relative wind, but meanwhile, thanks to an extraordinary grant conceded by the " Federazione Politecnica " of the R. Istituto Superiore di Ingegneria of Turin, the Laboratory has been able to acquire a new balance of the ordinary type with wire suspension system for the model and weights for the balancing of the forces transmitted. This balance enables measurements to be made of the resultant force and resultant moment on bodies immersed in the stream, in the general case in which the system of the pressures exercised on these bodies by the relative wind does not admit of a plane of symmetry (*e.g.*, aeroplane in a side wind, aerofoil in the airscrew slipstream). The balance, which was made at Göttingen by the G. Bartels firm of K. Reichert, under the direction of Professor Betz, is shown in Fig. 1. It fulfils the essential requirements of excellent sensitivity (with 100 kg. load the balance is sensitive to differences of 1 gramme) and independence of the measurements of the rolling, yawing, pitching moments, and longitudinal and lateral forces, so that these quantities are deduced *directly* and not as the sum or difference of two measurements. This characteristic is of the greatest importance as regards the *accuracy* of the determination, in particular with regard to the rolling and yawing moments which, in the cases of greatest interest technically, are small in comparison with the quantities directly measured and from which they have to be deduced.

Thus the balance is a most valuable gift for which the Laboratorio di Aeronautica of Turin tenders grateful thanks to the Fondazione Politecnica Piemontese.

3. The suspension of the model and the manner of the transmission of the aerodynamic action on the model to the balance are shown in Fig. 1.

The model is arranged with its plane of symmetry, or, as a rule, with the plane taken as basic reference plane, vertical (so that the angle of the plane relative to the axis of the tunnel is directly the side wind angle δ), and it is connected to the balance by wires a, b, c, d kept in tension by suitable counterweights.

The wires $a_1 a_2$ which are attached on the model at points O_1 and O_2 are vertical and arranged symmetrically with respect to the reference plane defined above.

Their other ends run to points D and D' of a lever L capable of oscillation about the spindle CC', horizontal and in the plane of symmetry, which in its turn is carried by the beam G pivoting about spindle $A-A'$ also horizontal but normal to $C-C'$. Lever L and beam G control lever D through the articulated rods H

and H'; the fulcrum F of D is carried on vertical rod N and lies in the same vertical plane passing through $A-A'$. Rod N is connected at its other end to the horizontal arm B_r of the balance, and the force transmitted by it is balanced, for values of the force multiples of 100 grammes, by the addition of weights in the scale pan carried by the same rod N, and for values of the gramme units by moving a rider weight on the balance arm B_r.

Beam G controls further through the vertical rod N', on the other side of the frame, the balance B_p and the force transmitted by N' is balanced in a manner

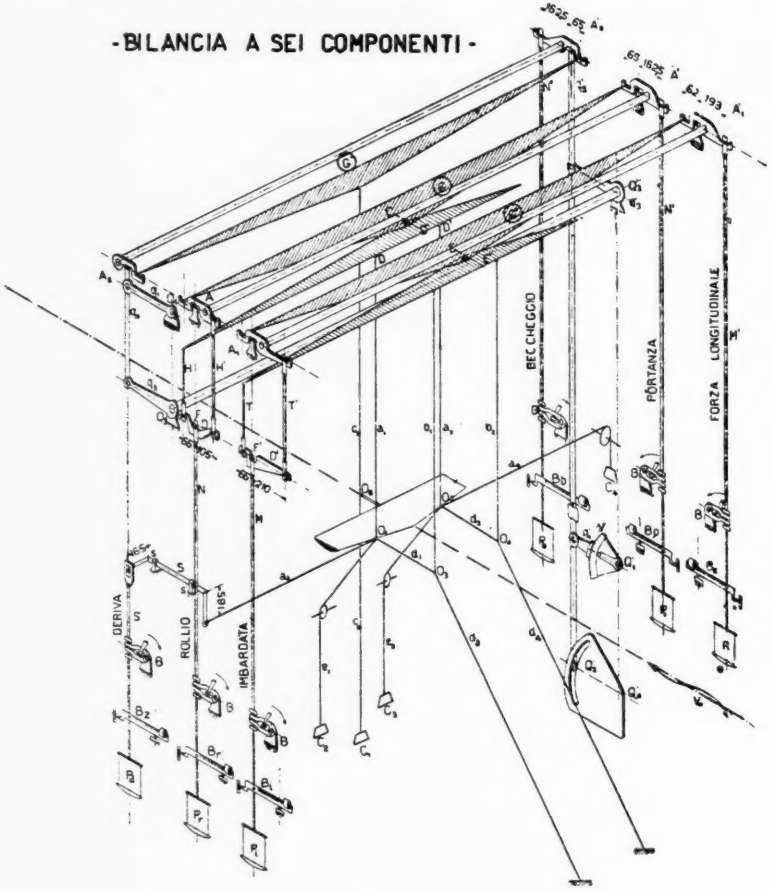


Fig 1.
(See text for description.)

similar to that described for B_r, with weights in the pan carried by N' and with rider weight on the arm of B_p.

Points O_1 and O_2 on the model are also the points of attachment of a wire a_3, which is horizontal and in the direction O_1O_2, and of wires d_1d_2, also horizontal and normal to a_3. Wire a_3 is connected at its other end to a bell crank lever S, pivoted about spindle ss', horizontal and normal to AA' and hence to O_1O_2, which controls balance B_z through the vertical rod S' articulated on itself.

Wires d_1 and d_2 run respectively to intersections O_3 and O_4 to which also run wires b_1 and b_2 vertical and parallel with a_1a_2, and wires d_3d_4 which lie in the vertical planes d and b are inclined to the horizontal at an angle $\beta = 51^\circ\ 15'$, and are fixed to the frame of the balance at their other ends. Wires b_1 and b_2, on the other hand, are connected to the lever L' the fulcrum of which EE', parallel with CC', is carried by beam G' in an exactly similar manner as that described for L and G. The vertical rods T and T', articulated respectively on

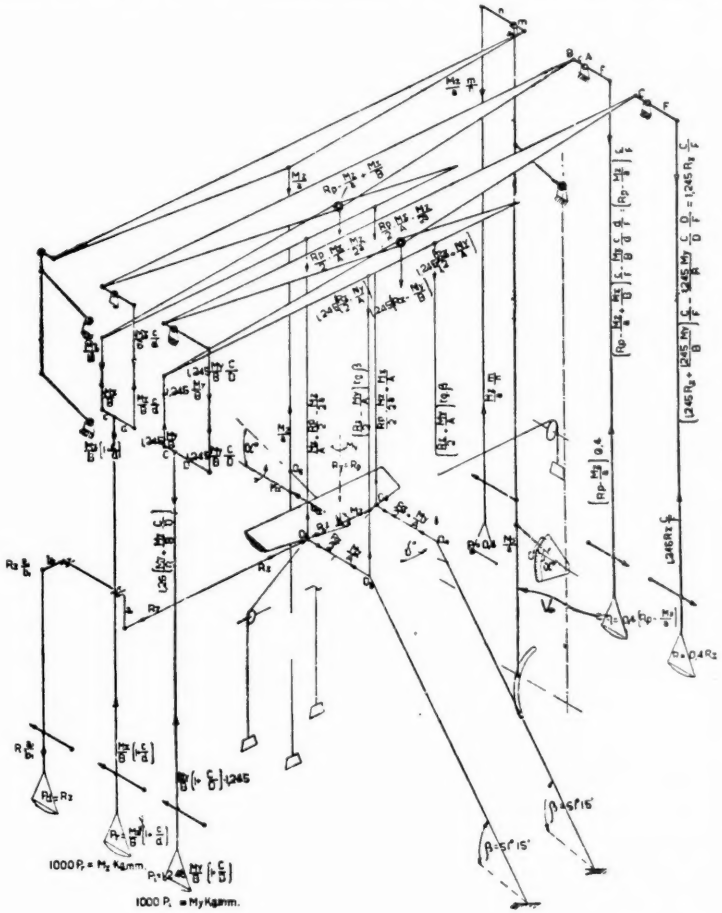


Fig. 2.
(*See text for description.*)

L' and G', control lever D' the fulcrum of which F' is carried by the vertical rod M and lies in the same vertical plane as that containing the fulcrum $A_1A'_1$ of beam G. M transmits its action to balance B_1, whilst G' through the medium of vertical rod M' controls balance B_2.

Point O_3 is the point of attachment for a wire c_1, vertical and connected to the beam G'', which is capable of oscillation about fulcrum $A_2A'_2$, parallel with

AA', and controls balance B_b through vertical rod N''. The fulcrums $A_2A'_2$ of G'' are carried by the two linked quadrilaterals (q_1, q_2, q_3), (q'_1, q'_2, q'_3) constituted by the rods q and q' which are highly rigid and have their fulcrums fixed at points Q_1, Q_2, Q'_3, Q'_1, Q'_4 lying in the same vertical plane passing through O_1,O_2, that is by the forward points of attachment of the model. The arm $Q'_2Q'_4$ of the quadrilateral may be fixed in any position and a pointer mounted on the vertical rod q'_1 moving in front of a suitable graduation indicates its inclination. Thus similarity between the rotations of the sides q'_1, q'_3, q_1, q_3 and that of the model about axis O_1O_2 is positively achieved, so that the incidence of the model is seen directly by reading off scale V.

The frame of the balance is mounted at present on circular rails, so the balance as a whole can be rotated about the vertical axis lying in the plane of symmetry and normal to O_1 and O_2 at its mid-point. The Director of the Laboratory has planned, however, a suspension system for the balance in which the balance would be suspended from an overhead pylon carried on a kind of travelling crane which, whilst allowing rotation of the balance about the above defined axis, would also allow a motion of translation of the balance as a whole in any direction. Fundamental advantages of this arrangement (overhead suspension) are that it allows greater freedom in the suspension of the model so that the side wind angles can be increased, and—above all—simultaneous use of the balance just described and of an airscrew balance indispensable in tests for airscrew interference on the other parts of an aircraft.

4. To define the action exercised by the air stream on the model a system of three co-ordinate orthogonal axes with origin at point O, or mid-point of the segment O_1O_2, must be assumed. The y axis is the vertical straight line passing through O, the z axis is O_1O_2 itself, whilst the x axis, normal to the plane yz, is parallel with the fulcrums CC', EE'. Let R_x, R_y, R_z denote the three components of the resultant force on the model in the direction of the selected axes, transposed to pass through O, whilst M_x, M_y, M_z are the moments about the same axes (Fig. 2).

The resultant force and moment acting on the model are balanced by the tension set up in consequence in the six wires connecting it to the balance, so that exactly we have:—

Wires d_1 and d_2	tension in	d_1	$T_1 = R_x/2 - M_y/A$	where $A = O_1O_2$.
	,,	d_2	$T_2 = R_x/2 + M_y/A$	
Wires a_1 and a_2	,,	a_1	$T_3 = R_y/2 + M_x/A - M_z/2a$	where $a = OO_5 = 300$ m.
	,,	a_2	$T_4 = R_y/2 - M_x/A - M_z/2a$	
Wire a_3	,,	a_3	$T_5 = R_z$	
Wire a_4	,,	c_1	$T_6 = M_z/a$	

The tensions T_1 and T_2 divide up at O_3 and O_4 along the directions of the wires d_3 and d_4 (at an angle $\beta = 51^\circ\ 15'$ to the horizontal) and b_1 and b_2 which are vertical. Hence in these we have: $t_1 = \tan\beta T_1 = 1.245\ T_1$; $t_2 = \tan\beta T_2 = 1.245\ T_2$.

t_1 and t_2 are transmitted to lever L' and their moment about fulcrum EE' is balanced by rod T, which is thus subjected to a force $t_3 = 1.245\ M_y/B$, in which B denotes the distance between T and EE'. t_3 is transmitted to D', and the moment about fulcrum F' of D' is balanced by T' which reacts with force $t_4 = 1.245\ (M_y/B)\ (C/D)$, in which C and D are now respectively the lever arms of t_3 and t_4 about F'. The beam G' is thus acted upon by $t_1 + t_2 + t_3 = 1.245\ (R_x - M_y/B)$ applied at the pivot point of T'.

The total moment about spindle AA', is thus:—

$$1.245\ (R_x + M_y/B)\ C - 1.245\ (M_y/B)\ C = 1.245\ R_xC$$

and is balanced by rod M' which is subjected to a force

$$t_5 = 1.245\ (C/F)\ R_x$$

F being the lever arm of the force about $A_1A'_1$.

With $C=62$ mm. and $F=193$ mm., we get $C/F=0.321$ and hence, if R is the weight in kg. which must be added to the pan of balance B_x in order to restore equilibrium, we have $R=R_x/2.5$ or, in other words, *the weight which must be added on* B_x *multiplied by* 2.5 *gives the value of the component along the x axis of the force exercised by the air stream on the model.*

The force transmitted to balance B_1, on the other hand, is equal to t_3+t_4 and hence to $1.245\,(M_y/B)\,(1+C/D)$, and since $C=62$ mm., $D=206$ mm. it follows that the weights added on B_1 to restore equilibrium are given by $P_1=1.62\,(M_y/B)=M_y$, B being equal to 1.62 metres.

In other words: *the weight in grammes which must be added on balance* B_1 *gives the moment in kilogramme-millimetres about the y axis.*

In a manner exactly similar to that described above the tensions T_3 and T_4 of wires a_1 and a_2 are transmitted to balances B_r and B_p. And if we denote by P_r and P_1 the weights in kg. applied respectively to B_r and B_p, we get:—

$$P_r=1.62\,(M_x/B)=M_x$$
$$P_1=0.4\,(R_p-M_z/a)$$

Or, in other words, *the weights added on balance* B_r *in grammes define directly the moment about the x axis in kilogramme-millimetres, whilst those added on balance* B_y *multiplied by* 2.5 *give the value* R_p-M_z/a.

Wire a_3 subjected to tension $T_3=R_z$ acts on the bell crank lever S and the moment of T_3 about ss' is balanced by vertical rod S', and since the two arms of lever S are equal, the force on S' must be equal to R_z. And hence $P_6=R_z$ also, in other words, *the weight added on balance* B_z *gives directly the measure of the component of the force on the model in the direction z.*

Wire c_1 transmits its pull $T_6=M_z/a$ to the beam G'' and the moment of T_6 about the fulcrum of the latter is balanced by rod N'' on which therefore the acting force is:—

$$(M_z/a)\,(m/n)=0.4\,(M_z/a)$$

since $m=65$ mm., $n=162.5$ mm.; and n and m being respectively the lever arms of the forces on N'' and of T_6 about the pivot pin of G''. It follows that *the weights in grammes added on balance* B_b *multiplied by* $2.5\,a=3/4$ *gives the moment of the air force with respect to axis* O_1O_2, *whilst the sum of the weights on* B_b *and* B_p *multiplied again by the same factor* 2.5 *is equal to the total lift of the model.*

If the forces and moments are referred not to the x, y, z axes fixed in the balance but to the wind axes X, Y, Z (X in the direction of the air stream, Y vertical, Z normal to plane XY), we have:—

$$R_p=\text{lift}=R_y;$$
$$R=\text{drag}=R_x\cos\delta-R_z\sin\delta;$$
$$R_z=R_z\cos\delta+R_x\sin\delta;$$

whilst the corresponding moments are defined by identical expressions in the form of functions of M_x, M_y, M_z.

The 600 mm. Wind Tunnel

5. This wind tunnel, designed in all its details by Professor Ferrari, was built essentially as an auxiliary tunnel for use in addition to the large 2 metres diameter wind tunnel, for tests such as calibration of anemometers, experiments in connection with lectures, investigation of vibration phenomena and, finally determination of friction resistances and velocity curves in the boundary layer adhering to obstructions in laminar and turbulent flows, for which purpose it is provided with a bench allowing micrometric motions of the measuring device (hot wire anemometer, pitot tube). The tunnel has been used also for tests intended to show the steadiness of the stream and the velocity distribution in

the cylindrical working section, as also the influence on these characteristics of the various details of design of the wind tunnel, with the object of utilising the results for a contemplated modification of the large wind tunnel.

6. The 600 mm. wind tunnel, shown in Fig. 3, is of the open jet type with

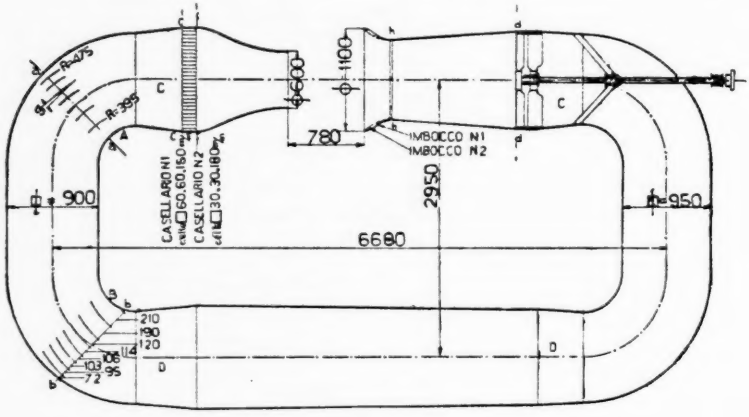


Fig. 3.

single return duct, like the classical example at Göttingen. It differs from the Göttingen tunnel in that right-angled deflections of the stream with cascades at the points where such deflections occur, are avoided, the deflection of the stream being achieved by circular bends connecting the straight portions of the tunnel at right angles to each other. With a view to correcting the expected dissymmetry of the stream, two cascades are fitted in the two bends *A-B* ahead of the cylindrical section at sections *a-a* and *b-b*. The vanes are thin curved blades developed from cylindrical surfaces with directrix in the form of an arc of a circle; they are arranged so as to obtain decreasing spacing from the tunnel wall with smallest radius of curvature to that with greater radius, with the object of setting up a greater resistance to the flow at the point where owing to centrifugal force the velocity tends to increase. The angle of incidence and width of the vane are designed so as to deflect the direction of the velocity of the mass of air constituting the stream through 90°.

The return passage is circular in section except for the bends, which are of square section. The transition from the square to the circular section is gradual and effected through the portions *C-D* seen in Fig. 3. The honeycomb, with square mesh, is fitted at section *c-c* which is also the greatest cross-section of the passage. A honeycomb, or straightener, with cells $60 \times 60 \times 150$ mm., and another with smaller cells $30 \times 30 \times 180$ mm. were fitted in turn. The ratio of the area at the greatest section of the tunnel to that of the experimental chamber is 3.25; the ratio of the length of the open jet to its diameter is 1.18; and the ratio of the smallest diameter of the collector to that of the jet is 1.36.

The power plant is mounted at section *d-d*, that is fairly near the collector, which arrangement is favourable to steadiness of flow. In actual fact the flow undergoes considerable disturbance as owing to viscosity effects the jet carries along with it into the duct a considerable mass of air which is discharged back into the surroundings partly by the opposition offered by the contraction of the collector flare and partly by escaping through slits at *h-h*. As a consequence of the action of this mass of air the stream is stemmed and the velocity curve in a section just below *h-h* is slightly irregular with notable irregularities along a

relatively extensive portion adjacent to the walls. The airscrew as it imparts greater acceleration to the slower fluid particles is an auxiliary to viscosity in steadying the stream.

The power plant consists of a four-bladed airscrew and an eight-bladed counter-screw mounted behind the first. The motor driving the screw develops a power of 30 h.p. at 3,000 r.p.m. The velocity of the stream for this r.p.m. of the screw is 60 metres per second.

7. The tests of this tunnel were carried out with great skill and industry by Ing. P. Cicala, their purpose being to ascertain :—

(*a*) The velocity distribution in a cross-section of the jet with the following arrangements in the tunnel :—

(1) Without cascades, with honeycomb No. 1 (large cells).
(2) Without cascades, with honeycomb No. 2 (small cells).
(3) With cascades and honeycomb No. 2 (small cells) and with collector No. 1 (slightly divergent).
(4) With cascades, with honeycomb No. 2, with collector No. 2 (greater divergence).

(*b*) The diffusion of the section of the stream undisturbed by the air carried along at the jet boundaries owing to viscosity.

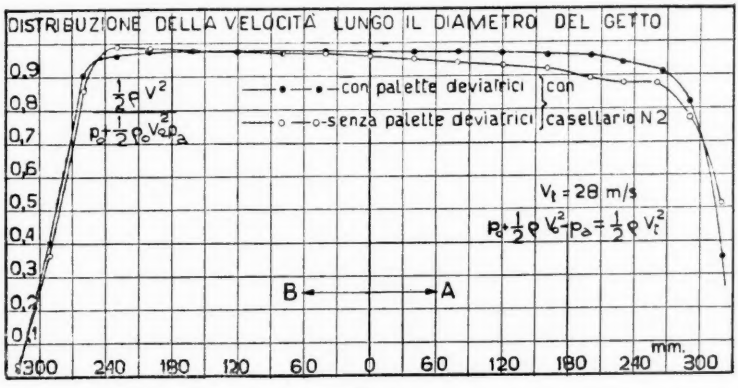


Fig. 4.

The investigations grouped under (*a*) were effected either by direct measurement of the velocity along a diameter by the differential method using a pitot tube and with differential alcohol micro-manometers, or by measurement of the rolling moment on an aerofoil model, 119 × 410 mm., rectangular in plan and having the section shown in Fig. 5, using the six-forces balance described in the preceding chapter. The results of the tests are shown graphically in Fig. 4, the abscissæ being the distances from the axis of the measurement points on the horizontal diameter of the jet, and the ordinates the ratios of the dynamic pressures $\frac{1}{2}\rho V^2$ measured at the same points to the theoretical dynamic pressure (Bernouilli's formula) $\frac{1}{2}\rho V^2{}_o + p_o - p_a$, in which $p_o + \frac{1}{2}\rho V^2{}_o$ is the total pressure measured by pitot tube at section *f-f* just behind the honeycomb, and p_a the atmospheric pressure which is also the static pressure of the jet. The existence of a dynamic pressure $\frac{1}{2}\rho V^2$ gradient in the direction of the radius, well-marked with absence of the honeycomb, is very clearly apparent. The curves show that :—

$$(d/d\xi)\ \{\ \tfrac{1}{2}\rho V^2/(p_o + \tfrac{1}{2}\rho V^2{}_o - p_a)\ \}\ (\xi = \text{relative radius} = r/R)$$

is roughly constant over all the horizontal diameter within the jet and equal to

0.08. In other words, *in the absence of deflecting vanes the transverse dynamic pressure gradient amounts to* 8 *per cent. of the dynamic pressure itself.* The cascades are shown to be highly efficient in producing uniform stream velocity; Fig. 4 shows clearly that there is no sensible pressure gradient in the useful portion of the section of the jet.

Exploration by pitot tube of the velocity field is not sufficient, however, to give a complete indication of the uniformity of the flow, as such exploration whilst revealing any differences in the *magnitude* of the velocity does not reveal with sufficient accuracy the possible dissymmetries in the *direction* of the velocity. Ing. Cicala's measurements of the rolling moment on a wing model with span equal to the useful diameter of the jet were designed to fill this lacuna. The results of the measurements, which owing to the sensitivity of the balance and the uniformity in time of the flow were effected with a very high degree of

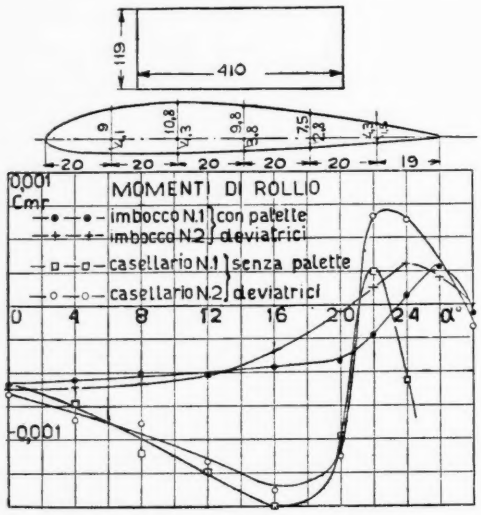


Fig. 5.

accuracy, are shown in Fig. 5. The curves of the coefficients of rolling moment c_{mr} referred to the span and wing area and given as function of the angle of incidence of the section, reveal clearly the existence of an irregularity in the direction of the velocity, such as might be produced by a vortex with axis coincident with the axis of the tunnel. This view is substantiated by the fact that even with zero lift the c_{mr} differs from zero and has roughly the same value for all the combinations tried. As in the neighbourhood of zero lift an irregular distribution of the velocity intensity has no appreciable influence and the cascades remove all dissymmetry from the stream, it follows that the moment can be produced only by irregularities in direction. Further, the rolling moment set up by irregularities in direction is proportional to the angular coefficient of lift $dc_p/d\alpha$, and thus varies very slowly with increasing incidence in the region of the small incidences, after which it diminishes with increasing rapidity until it cancels out in the neighbourhood of the incidence corresponding to the peak of the curve, whilst the moment set up by irregularity of the velocity is proportional to the lift coefficient c_p of the wing and hence increases with the incidence up to the value corresponding to $(c_p)_{max}$, after which it decreases. It will be seen in Fig. 5 that these very characteristics are manifested by the curves of the c_{mr} as a function of α for the two arrangements with and without cascades.

The essential importance of the tests described above consists in the fact that they reveal the existence of an irregularity in direction *which appears to be proper to the type of tunnel, and on which neither the shape of the collector or the length or depth of the cells of the honeycomb has any appreciable influence, as is shown by the curves of Fig.* 5. Neither can it be thought to be due to a continuation of the axial vortex of the airscrew not completely neutralised by that of the counter-screw, because the irregularity itself was found to be independent of the blade angle of the counter-screw. It is highly probable that the cause of the irregularity may be found in the changes of direction which the stream undergoes by the effect of the circular bends rather than by the cascades. It is,

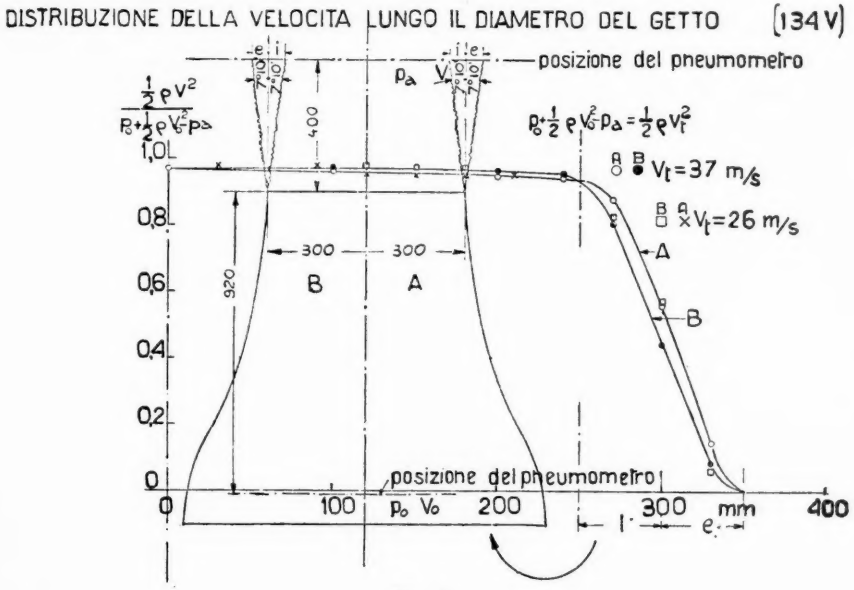


Fig. 6.

indeed, a known fact that in ducts of circular or square section with curvilinear axis secondary flows are generated in the cross-sections of the duct itself* owing to the combined effects of centrifugal force and friction along the walls, equivalent to those of two linked vortices located symmetrically with respect to the plane passing through the axis of the stream and through its centre of curvature. These vortices induce at the model a velocity which over all the span is in the direction of the span so that the wing is in a condition of being swept by a side wind. Moreover, if for any cause the two vortices have not the same circulation or are not located symmetrically with respect to the model (for instance as a result of the angle of incidence of the model) there is also a direct cause for irregularity in the distribution of the incidence of the wing along the span. Secondary flows, on the other hand, are not generated, or at least, have very low intensity, in curved ducts with sections having a considerable length in the direction normal to the motion and to the radius of curvature of the axis, as are

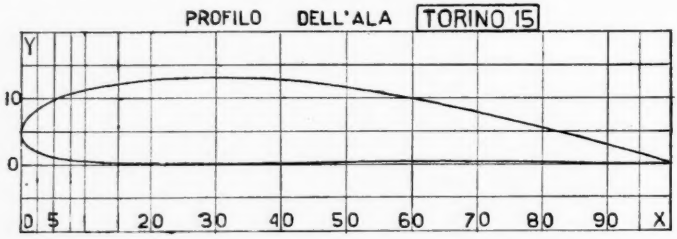
* Betz, Über turbulente Reibungsschichten an gekrümmten Wänden. Vorträge aus dem Gebiete der Aerodynamik und verwandter Gebiete, Aachen 1929.
Isaachsen, Innere Vorgänge in strömenden Flussigkeiten und Gasen. Z.V.D.I., Bd. 55, 1911.

the passages included between two consecutive vanes of a cascade at the bends of a Göttingen type tunnel.

8. The results of the experiments intended to determine the region of the stream in which the velocity remains uniform, that is, is not disturbed by the air carried along at the boundaries of the jet, are shown in Fig. 6. This graph shows that the region of uniform flow is bounded by a cone the generators of which have their base on the nozzle and form an angle of 7° 10′ against the axis of the stream, whilst the region of zero velocity is bounded by another cone with base on the same nozzle, the generators of which also form an angle of 7° 10′ against the axis, and hence an angle of 14° 20′ relative to the generators of the first cone. It is interesting to note that according to Tollmien's theory* based on the assumption that the fluid flow is everywhere turbulent and that hence the free convection path at any point is proportional to the distance between the section on which the point is situated and the nozzle, the two surfaces bounding the stream with uniform velocity and the area with zero velocity are as in the case described above conical surfaces, but with the difference of a considerable discrepancy as regards the values of the angles β between the generators of these cones and the axis of the jet. Exactly, assuming that for the inner cone angle $\beta = 7° 10'$, the angle of the outer cone should be:—

$$\beta_1 = \text{arc tan } (2.04/0.981) \text{ tan } \beta = 14° 30'.$$

This discrepancy between the experimental results and those from theory, which have also been confirmed by other experiments, may probably be attributed to the fact that over a certain length—relatively more extended in the tests dealt with here—the flow is laminar and not turbulent.



X	0	2,5	5	7,5	10	15	20	30	40	50	60	70	80	90	95	100
Ys	4,3	8,2	9,45	10,3	11,2	12,1	12,7	13	12,9	11,4	9,81	7,86	5,57	3,03	1,6	0,2
Yi	4,3	1,71	1,1	0,75	0,54	0,2	0,05	0	0,05	0,1	0,15	0,2	0,15	0,08	0,02	0

Fig. 7.

In any case the notable reduction of the useful area for tests, due to the diffusion of the jet, is clearly shown, as a consequence of which in the wind tunnel under consideration the diameter D which is 600 mm. at the nozzle is actually reduced to 500 mm. (or to 0.83 D) at a distance from the nozzle as small as 400 mm. (or 0.67 D).

Electric Tanks

9. The electric tank installation for the study of aerodynamic fields by a method based on the analogies between aerodynamics and electro-dynamics, was improved by Professor Ferrari who had been responsible for the design of the initial installation. The installation is now suitable for the determinations of the

* Tollmien, Berechnung turbulenter Ausbreitungsvorgänge. Zeitschrift für angewandte Mathematik und Mechanik, 1926.

fields about cylindrical obstructions or bodies of revolution with Oseen wake,* and of the field about a wing of finite span applying the analogy indicated by Pérés and Malavard† for the calculation of the distribution of the circulation along the span of the wing.

Test Results

The methods and conventions adopted in the first series of the Laboratory's " Rendiconti Sperimentali " are again used here in giving the results of the tests under review.

The models again bear as distinctive mark the name " Torino," and the number sequence is continued from the first series. The tests on the models with numbers 15 to 30 and 33 to 35 were carried out at the request of the Società Industriali e di Tecnici delle Costruzioni Aeronautische, and hence *forms, profiles and proportions of the models are the property of the authors who have given permission for publication subject to the reservation of all their rights.* The tests relative to the models " Torino 30, 31, 32," carried out with a view to investigating the influence of the running airscrew on the aerodynamic characteristics of the tail surfaces of an aeroplane, constitute part of a series of systematic investigations now in course at the Laboratory and were undertaken at the demand of the Air Ministry. The tests were carried out by Ing. L. Faraggiana and Ing. L. Elia, using the balances described in the Series 1 Reports.

" Torino 15, 16 17 " (Figs. 7, 8, 9, 10, 11, 12)

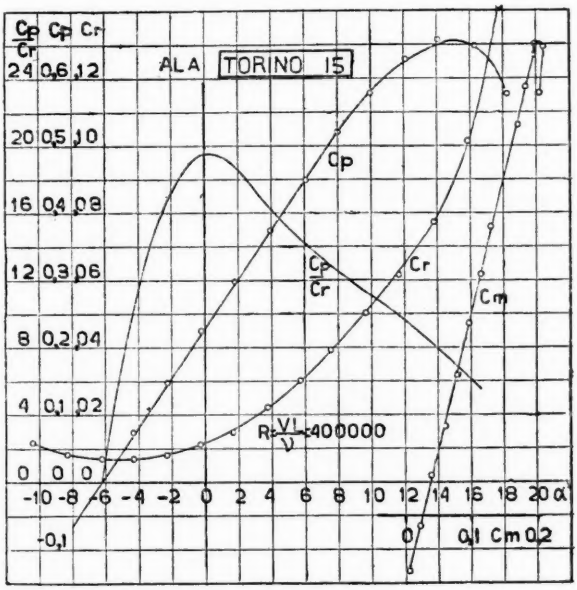


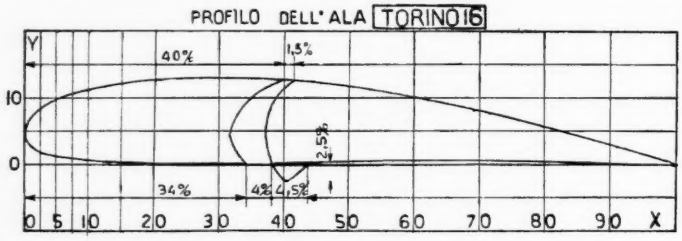
Fig. 8.

The " Torino 15 " wing, rectangular in plan, has an aspect ratio 5 and constant section along the span, the maximum thickness of the section being

* C. Ferrari, Le analogie elettriche nell'aerodinamica. Conferenze di Fisica e Matematica. R. Università e R. Scuola di Ingegneria di Torino, 1934.

† Pérés and Malavard, Comptes Rendus de l'Académie des Sciences. II Semestre 1932.

13 per cent., situated at a point 0.30 of the chord from the leading edge. The " Torino 16 " and " Torino 17 " wings, identical as regards plan form with the " Torino 15," have a section developed from the basic section of the " Torino 15 " by opening a slot, the shape and dimensions of which are shown in Figs. 8 and 11, situated respectively at 0.34 and 0.49 from the leading edge. The



X	0	2,5	5	7,5	10	15	20	30	40	50	60	70	80	90	95	100
Ys	4,3	8,2	9,7	10,5	11,3	12,3	12,8	13	12,7	11,8	10,1	8,15	5,9	3,15	1,6	0,2
Yi	4,3	1,8	1,2	0,9	0,6	0,2	0,03	0	0,05	0,1	0,15	0,18	0,17	0,1	0,02	0

Fig. 9.

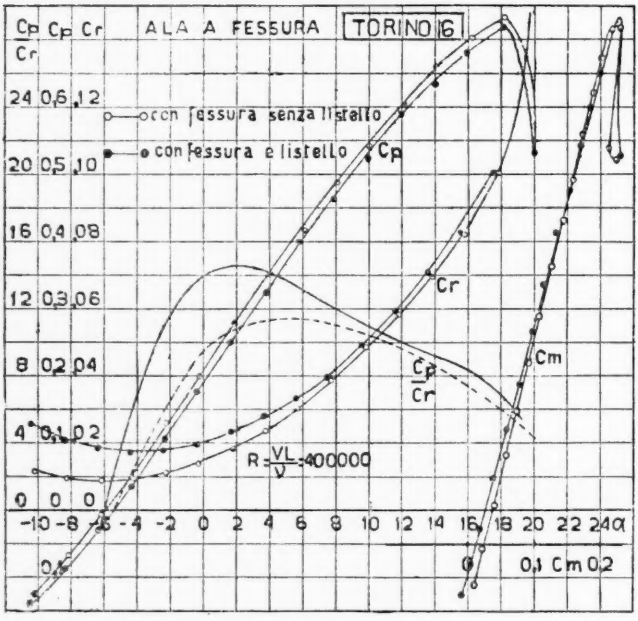


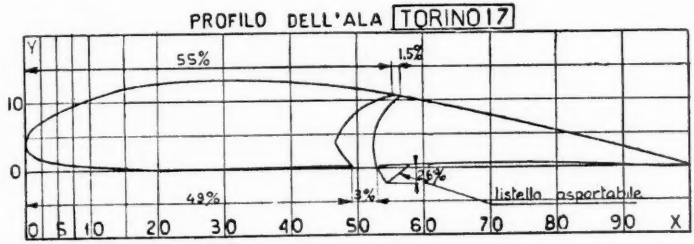
Fig. 10.

tests on these aerofoils were intended to ascertain the influence on the lift and drag characteristics of the sections of both the slot location and the presence of a projection on the under surface immediately behind the slot. This projection is seen in Figs. 9 and 11, and the curves relating to the wings with this projection are denoted in the graphs, Figs. 10 and 12, by the word " listello " (stringer).

Both the slot and stringer run the whole length of the span. The most interesting results of the tests are summarised in Table I.

TABLE I.

	$c_{p\,max}$	c_p/c_r for $c_{p\,max}$	$a°$ for $c_{p\,max}$	$c_{r\,min}$	$a°$ for $c_p = 0$	$(dc_p/da)_{max}$	$(c_p/c_r)_{max}$	$a°$ for $(c_p/c_r)_{max}$	Focus position	c_{mf}
Basic profile ...	0.65	7.22	15°	0.007	6° 12′	2.1	19.6	0°	0.25	0.04
Profile with slot at 0.34 c. ...	0.73	7	18°	0.009	6°	2	14.5	2°	0.25	0.04
Profile with slot at 0.34 and stringer	0.72	6	18°	0.017	5° 30′	1.98	11.5	5°	0.28	0.025
Profile with slot at 0.49 c. ...	0.73	7	18°	0.008	6°	2.05	15.2	1°	0.25	0.04
Profile with slot at 0.49 and stringer	0.74	7	18°	0.016	5° 40′	1.97	11.9	4°	0.28	0.025



X	0	2,5	5	7,5	10	15	20	30	40	50	60	70	80	90	95	100
Y_S	4,1	7,2	8,75	9,8	10,9	12,1	12,7	13	12,8	11	10,1	8,01	5,65	3,0	1,6	0,2
Y_I	4,1	1,5	0,95	0,7	0,5	0,2	0,05	0	0,05	0,1	0,15	0,2	0,17	0,1	0,02	0

Fig. 11.

The conclusions reached are:—

(*a*) The slot raises the maximum lift, the average value of which is about 12 per cent., the value for the basic section. The position of the slot and the presence of the stringer have a very slight influence on the $c_{p\,max}$ and on the incidence at which the latter occur; in fact $c_{p\,max}$ increases from the minimum of 0.72 corresponding to the arrangement with slot at 0.34 of the chord and with stringer, to the maximum of 0.74 with slot at 0.49 of the chord, again with stringer. The efficiency ϵ at maximum lift, which is 7.22 for the basic section, undergoes a slight deterioration as a result only of the slot, in both cases $\epsilon'=7$, the drop being thus not quite 3 per cent. The presence of the stringer, which with the most rearward position of the slot brings about no appreciable reduction, with the forward position gives $\epsilon=6.5$, thus a decrease of 10 per cent. relative to the initial figure. The efficiency of the stringer as aerodynamic brake is, however, particularly high at the lower incidences: thus $c_{r\,min}$, which the influence of the slot alone increases by hardly 20 per cent., by the addition of the stringer undergoes an increase of 135 per cent., and a more forward position of the stringer gives a somewhat greater effectiveness. With the slotted sections there is an increase of the angle at which $c_{p\,max}$ occurs, as compared with the basic section, and the angle, irrespective of the arrangement, is always 18°. The

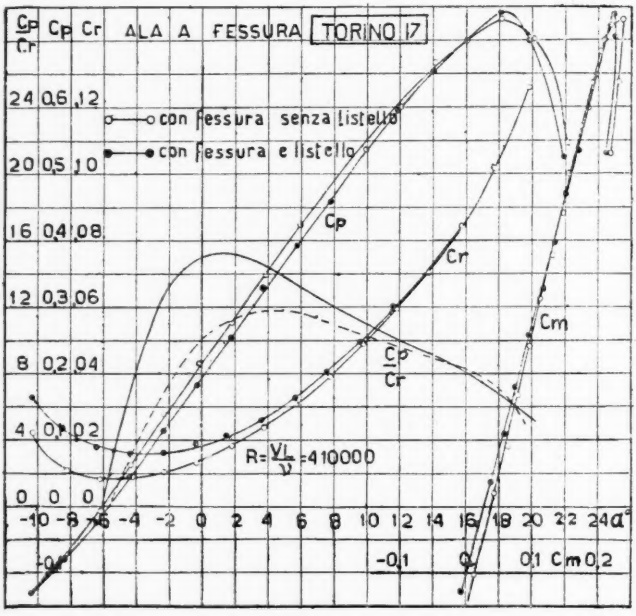

Cp Cr ALA A FESSURA TORINO 17
con fessura senza listello
con fessura e listello
Cp
Cr
Cm
Cp/Cr
R=Vl/ν =410000
-10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24α°
-0,1 0 0,1 Cm 0,2

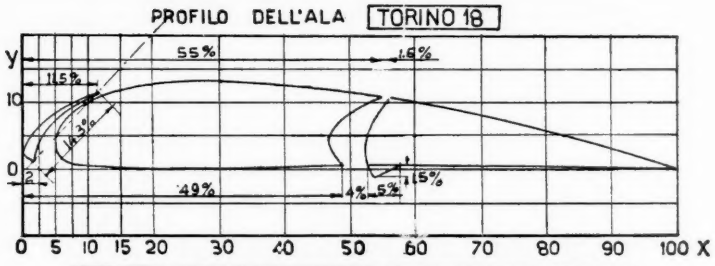
Fig. 12.

angle of no lift, on the other hand, undergoes a decrease owing to the influence of the stringers alone, the decrease being roughly the same for the two slot positions, and this variation of the angle of $c_p = 0$ is accompanied also by a decrease of the coefficient of focal moment of about 37 per cent. relative to the initial value. The position of the focus remains practically the same in every case.

" Torino 18, 19, 20, 21 " (Figs. 13, 14, 15, 16, 17, 18, 19, 20, 21)

The " Torino 18, 19, 20, 21 " wings are also developed from the basic section of the " Torino 15 " wing. They differ, however, from the basic section in that at the leading edge a Handley Page type of flap has been contrived, and at the trailing edge the " Torino 19, 20, 21 " wings are provided in addition with a camber flap capable of being set at any angle. Both the forward and rear flaps run the whole length of the span. At each slot a stringer was fitted in the manner described for the preceding tests. It was left in place even when the slots were masked. " Torino 20 " differs from " Torino 19 " by the profile of the slots designed as shown in Fig. 20, this profile being referred to in the following as " expanded slot " in contradistinction to the other, or " normal " slots. The " Torino 21," which as regards the slots is identical with the " Torino 19," differs from the latter by the camber flap, which has the profile shown in Fig. 15 and is provided with a small plane running along the whole span above the camber flap.

The series of tests carried out on these models link up with those on the " Torino 16 and 17 " wings, and were intended to determine the influence of the number and shape of the slots and shape and angle of the camber flap on the lift properties. The results are shown graphically in Figs. 14, 16, 17, 18, 19, 21, and are summarised in Table II.



X	0	2,5	5	7,5	10	15	20	30	40	50	60	70	80	90	95	100
Ys	2,6	6,2	8,45	10,2	11,2	12,2	13,1	13,3	12,6	11,5	10	8,16	5,6	3,0	1,7	0,2
Yi	2,6	–	–	0,5	0,3	0,2	0,3	0	0,1	–	0,2	0,15	0,17	0,17	0,2	0

Fig. 13.

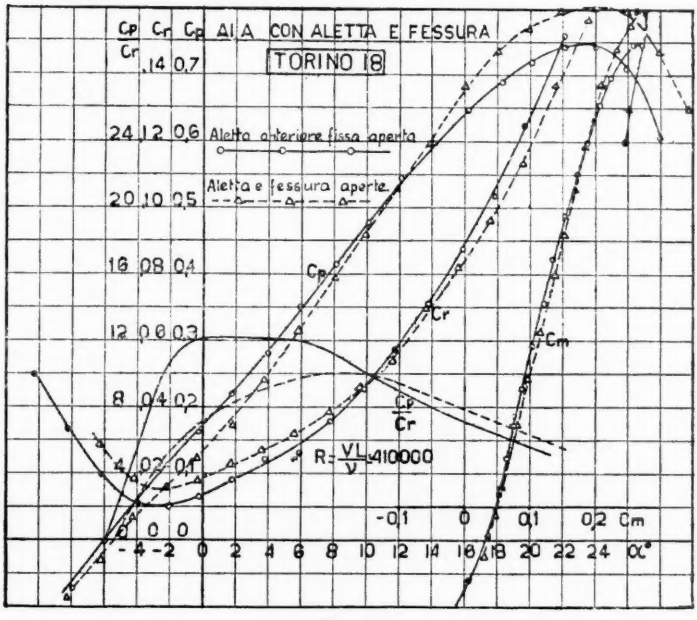
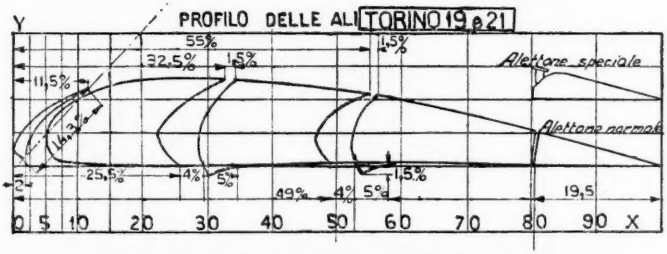

Cp/Cr Cr Cp
ALA CON ALETTA E FESSURA
TORINO 18
Aletta anteriore fissa aperta
Aletta e fessura aperte
Cp
Cr
Cm
Cp/Cr
R = VL/ν = 410000
-0,1 0 0,1 0,2 Cm
-4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24 α°

Fig. 14.



X	0	2,5	5	7,5	10	15	20	30	40	50	60	70	80	90	95	100
Ys	2,6	6,2	8,45	10,2	11,2	12,2	13,1	13,3	12,6	11,5	10	8,16	5,6	3,0	1,7	0,2
Yi	2,6	–	–	0,5	0,3	0,2	0,3	0	0,1	–	0,2	0,15	0,17	0,17	0,2	0

Fig. 15.

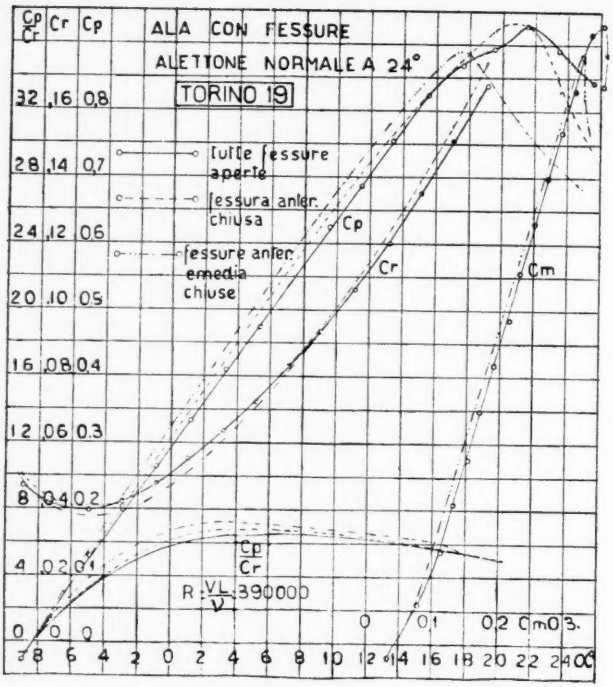

ALA CON FESSURE
ALETTONE NORMALE A 24°
TORINO 19
tutte fessure aperte
fessura anter. chiusa
fessure anter. e media chiuse
Cp
Cr
Cm
R = VL/ν = 390000

Fig. 16.

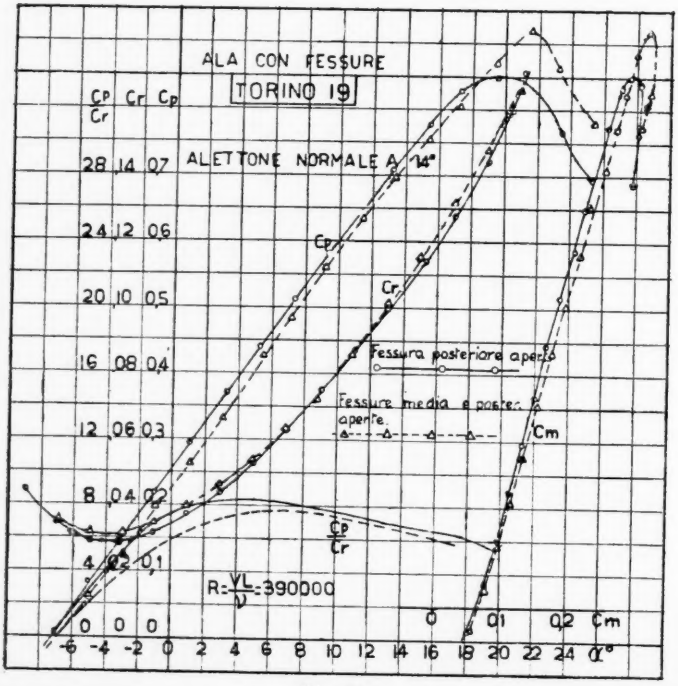

ALA CON FESSURE
TORINO 19
ALETTONE NORMALE A 14°
Cp
Cr
Fessura posteriore aperta
Fessure media e poster. aperte
Cm
R = VL/ν = 390000

Fig. 17.

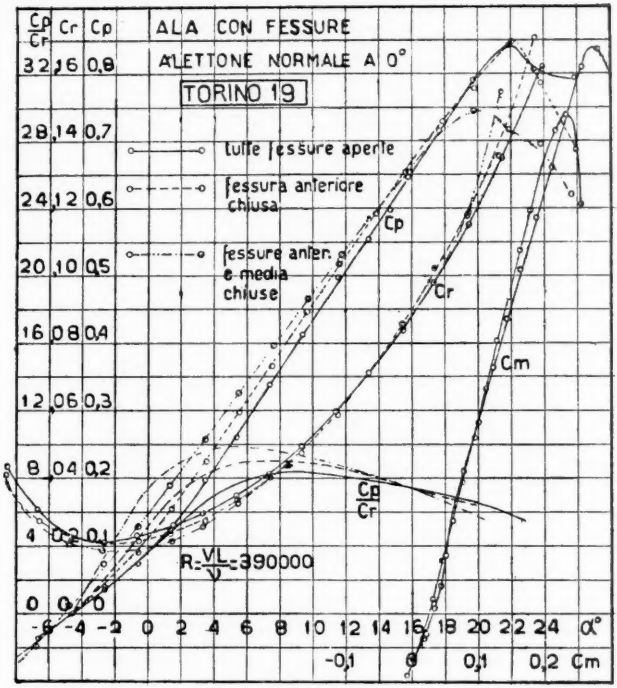

Cp/Cr Cr Cp
ALA CON FESSURE
ALETTONE NORMALE A 0°
TORINO 19
tutte fessure aperte
fessura anteriore chiusa
fessure anter. e media chiuse
Cp
Cr
Cm
Cp/Cr
R=VL/ν=390000
α°
Cm

Fig 18.

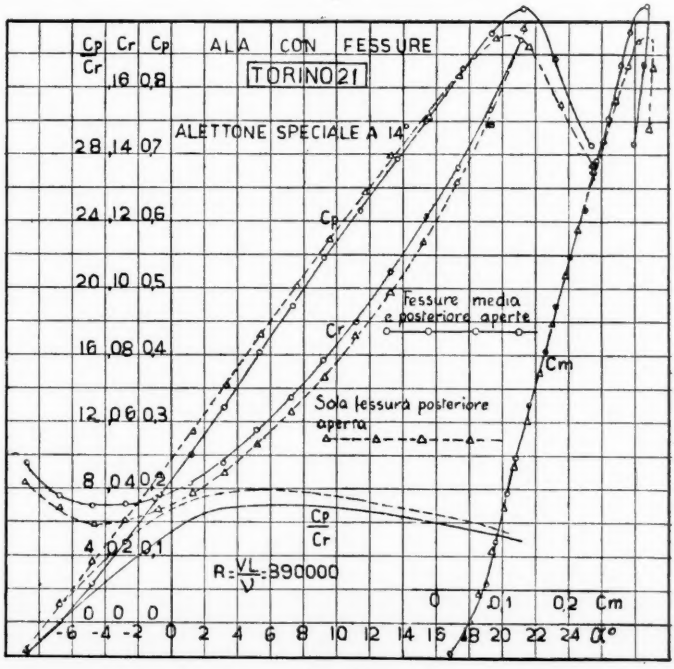
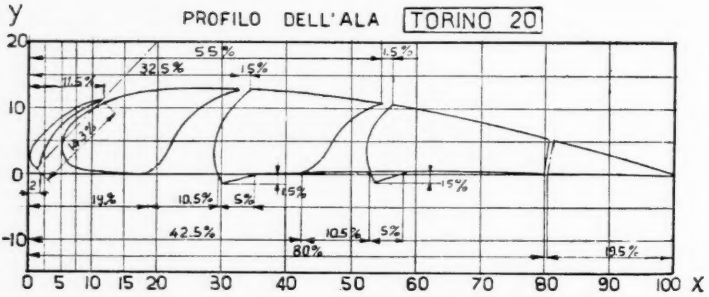

Cp/Cr Cr Cp
ALA CON FESSURE
TORINO 21
ALETTONE SPECIALE A 14°
Cp
Cr
Fessure media e posteriore aperte
Cm
Sola fessura posteriore aperta
Cp/Cr
R=VL/ν=390000
α°
Cm

Fig. 19.



X	0	2.5	5	7.5	10	15	20	30	40	50	60	70	80	90	95	100
y_s	2,6	6,2	8,45	10,2	11,2	12,25	13,1	13,3	12,6	11,5	10	8,16	5,6	3,0	1,7	0,2
y_i	2,6	–	–	0,5	0,3	0,2	1,2	0	0,5	–	0,15	0,2	0,17	0,1	0,2	0

Fig. 20.

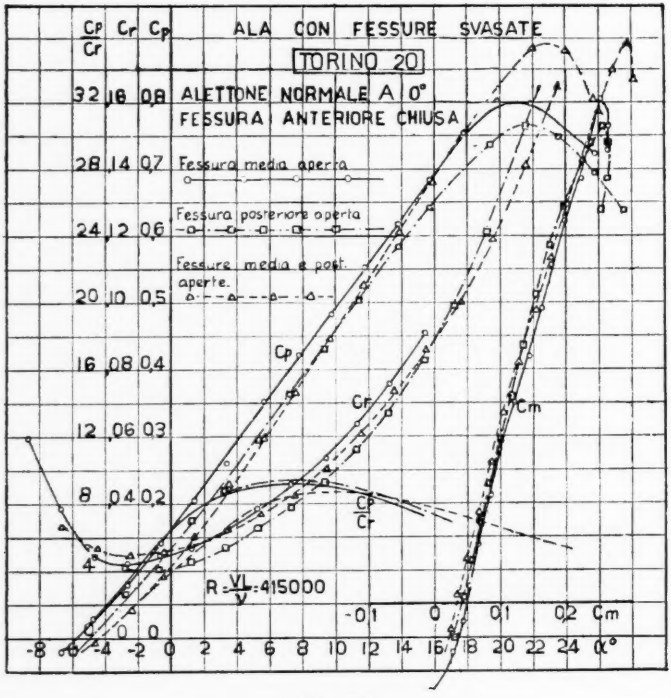


Fig. 21.

TABLE II.

	$c_{p\,max}$	c_p/c_r for $c_{p\,max}$	$a°$ for $c_{p\,max}$	$c_{r\,min}$	$a°$ for $c_p=0$	$(c_p/c_r)_{max}$	Position of Focus	c_{mf}
Basic profile	0.05	7.22	15°	0.007	−6° 12′	19.6	0.25	0.04
Profile with fixed H. P. flap	0.745	5	23°	0.01	−6°	12	0.25	0.03
Profile with H. P. flap and slot at 0.55 c.	0.8	5	23°	0.015	−5° 30′	10	0.25	0.03
Profile with H. P. flap, slot at 0.325 and 0.55 c. camber flap neutral	0.84	5.9	22°	0.02	−4° 30′	8.2	0.25	0.02
Profile with H. P. flap closed, slot at 0.325 and 0.55, camber flap neutral	0.85	5.8	22°	0.021	−4° 30′	9	0.25	0.03
Profile with H. P. flap and slot at 0.325 closed, slot at 0.55 open, camber flap neutral	0.745	5.8	20°	0.018	−5°	10	0.25	0.025
Profile with H. P. flap closed, slots at 0.325 and 0.55 open, camber flap at 14 degrees	0.92	5.4	21° 30′	0.03	−7°	7.8	0.25	0.045
Profile with H. P. flap and slot at 0.325 closed, slot at 0.55 open, camber flap at 14 degrees	0.85	5.5	20°	0.028	−7°	8.2	0.25	0.05
Profile with H. P. flap and slots at 0.325 and 0.55 open, camber flap at 24 degrees	0.93	4.7	21°	0.04	−8°	6.5	0.25 (recedes for small a)	0.07
							0.50	0.045
Profile with H. P. flap and slot at 0.325 closed, camber flap at 24 degrees	0.89	5.7	17°	0.038	−8°	7	0.25	0.065
							0.50	0.05
Profile with H. P. flap closed, expanded slots open, camber flap neutral	0.88	5.5	23°	0.025	−4° 30′	8.6	0.25	0.025
Profile with H. P. flap and slot at 0.325 closed, slot at 0.55 open, camber flap neutral, expanded slots	0.76	5	22°	0.02	−4° 30′	9.5	0.25	0.03
Profile with H. P. flap and slot at 0.55 closed, slot at 0.325 open, camber flap neutral, expanded slots	0.8	5.3	22°	0.022	−5° 30′	9	0.25	0.03
							0.50	0.04
Profile with H. P. flap closed, normal slots at 0.325 and 0.55 open, special camber flap at 14 degrees	0.92	5	21°	0.035	−7°	7	0.25	0.05
Profile with H. P. flap and slot at 0.325 closed, slot at 0.55 (normal) open, special camber flap at 14 degrees	0.88	5.5	21°	0.03	−7° 30′	8	0.25	0.05
Profile with H. P. flap closed, slots at 0.325 and 0.55 open, camber flap at 24 degrees	0.93	4.8	21°	0.04	−8°	6.8	0.25	0.07
							0.50	0.05

In these tests the location of the slots is again shown not to be of essential importance as far as achievement of a high $c_{p\,max}$ is concerned. The Handley Page flap, which alone induces an increase of 14.5 per cent. in the $c_{p\,max}$, equal roughly to the increase occurring with single slots open, is far less effective than these when more than one slot is opened: the increase of the $c_{p\,max}$ rises from 14 to 31 per cent. when, to the slot located at 0.55 of the chord, that at 0.325 of the chord is added, whilst the increase is only 23 per cent. for the arrangement with one slot and the forward flap. Further, the $c_{p\,max}$ does not increase at all when the wing with two slots at 0.325 and 0.55 is provided with the small plane. Whereas the focus remains constantly for all arrangements at roughly 0.25 of the chord from the leading edge, the small plane induces a decrease of the coefficient of focal moment of the same order of magnitude as the decrease due to the stringer.

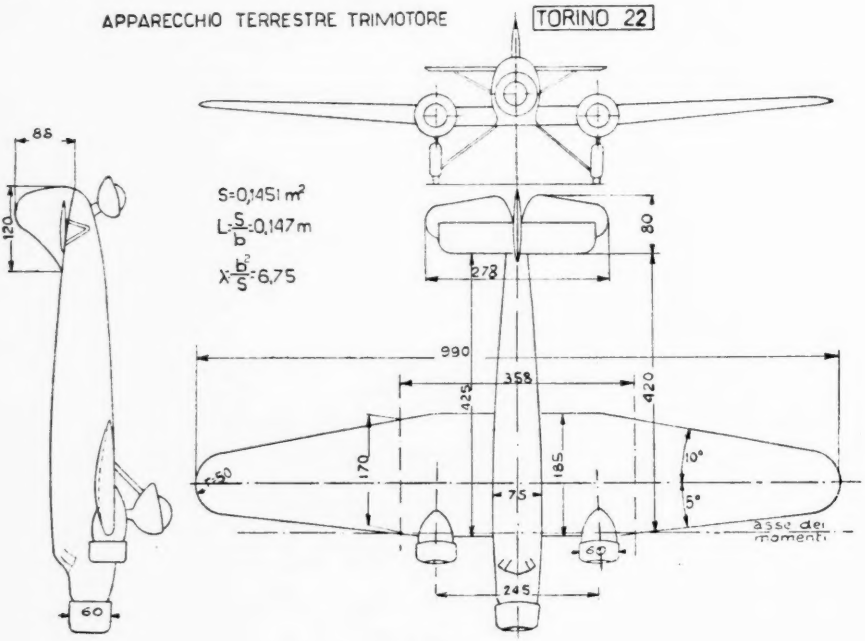


Fig. 22.

With the camber flap, which has a chord roughly equal to 0.20 of the wing chord, at an angle, $c_{p\,max}$ increases considerably, a value 41.5 per cent. higher than that for the basic section being reached with the arrangement with the two slots open. No further increase occurs, however, with increase of the angle of the flap from 14° to 24°. In addition to the effect on $c_{p\,max}$ the angle of the flap produces a considerable increase, even with respect to the preceding arrangements, in the maximum drag, so that at the high lift values a decrease of the efficiency is also recorded. The focus, which for the relative positive incidences is situated invariably at a point in the near vicinity of the forward fourth of the wing, for the incidences in the neighbourhood of zero lift shifts very rapidly towards the vertex of the section, tending to the limit position of 0.50. Simultaneously the focal moment, in which the angle of the camber flap had induced an increase

owing to the increased camber of the section by the angle of the flap, becomes somewhat reduced; for instance, for a flap angle of 24° the coefficient of focal moment, which for the relatively large incidence has the value 0.07, decreases for $c_p = 0$ down to 0.05.

It is further worthy of note that at the high lift values, for the Reynolds numbers at which the tests were executed, frequently two conditions of flow were manifested: one characterised by low lift, shown to be more stable for small Reynolds numbers, and the other, characterised by high lift, which, at the higher speeds used, is developed from the first by producing in the flow any sort of disturbance, *e.g.*, sudden increase of the tunnel wind speed. The low lift condition is not manifested with the arrangements with single slot, subject, however, to the presence of the Handley Page flap, which is shown to be highly effective in producing the turbulent condition about the profile.

A form of " expanded " slot, like that shown in Fig. 20, was found to be very effective, always from the point of view of obtaining a high $c_{p\,max}$. For instance, other conditions being equal, passing from the normal to the expanded shape, with the arrangement with the single rear slot the increase in $c_{p\,max}$ relative to that of the basic section was 13.8 per cent. in the first case and 17 per cent. in the second case.

The shape of the camber flap has only a very slight influence.

" Torino 22 " (Figs. 22, 23, 24, 25, 26, 27)

This is a three-engined landplane with completely cantilever, thick low wing. The engines are of the air-cooled radial type, the centre engine being mounted in the fuselage and the wing engines in fairings merging in the wing. The wing is made up of a rectangular centre section to which are connected the two

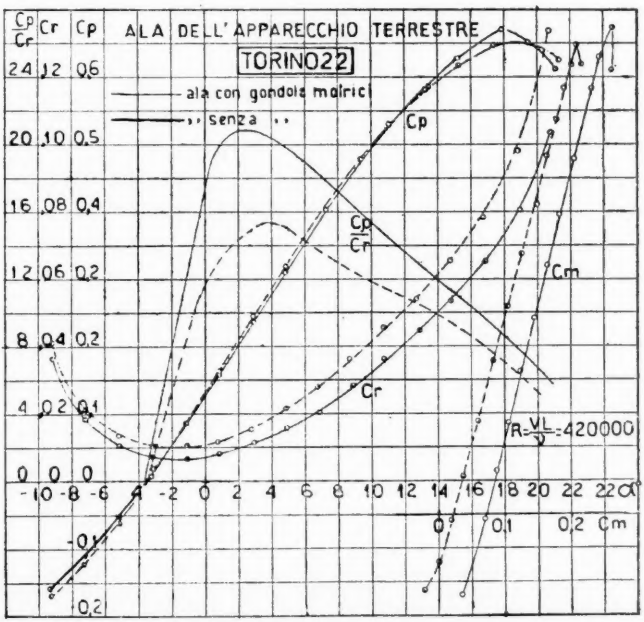


Fig. 23.

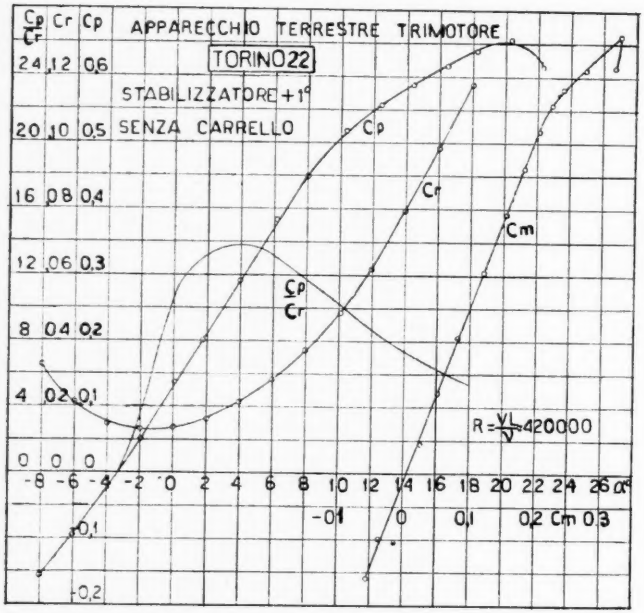

Cp/Cr Cr Cp
APPARECCHIO TERRESTRE TRIMOTORE
TORINO22
STABILIZZATORE +1°
SENZA CARRELLO
Cp
Cr
Cm
Cp/Cr
R = VL/ν = 420000
24 1,2 0,6
20 1,0 0,5
16 0,8 0,4
12 0,6 0,3
8 0,4 0,2
4 0,2 0,1
0 0 0
-8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24 26 α°
-0,1 0 0,1 0,2 Cm 0,3
+0,1
+0,2

Fig. 24.

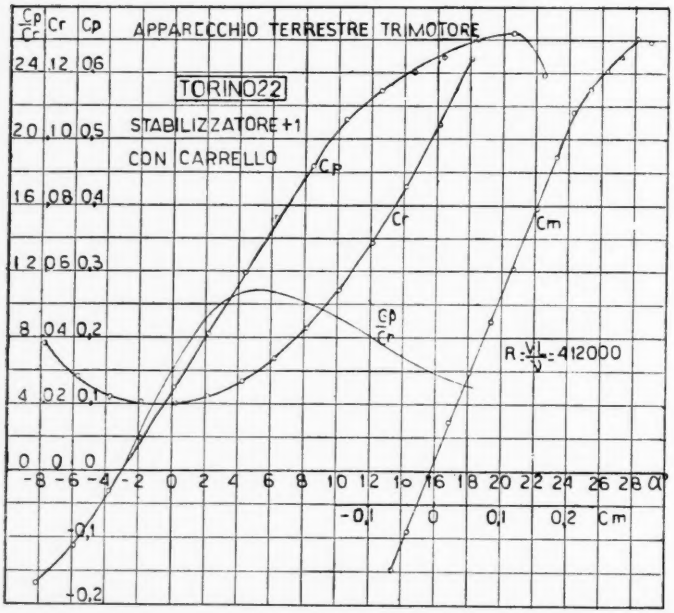

Cp/Cr Cr Cp
APPARECCHIO TERRESTRE TRIMOTORE
TORINO22
STABILIZZATORE +1
CON CARRELLO
Cp
Cr
Cm
Cp/Cr
R = VL/ν = 412000
24 1,2 0,6
20 1,0 0,5
16 0,8 0,4
12 0,6 0,3
8 0,4 0,2
4 0,2 0,1
0 0 0
-8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 α°
-0,1 0 0,1 0,2 Cm
-0,1
+0,2

Fig. 25.

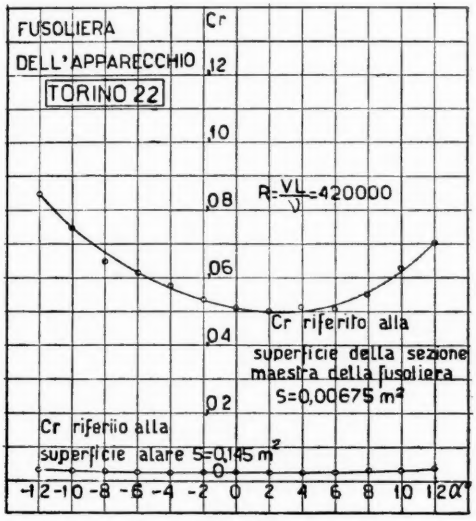

FUSOLIERA
DELL'APPARECCHIO
TORINO 22
Cr
,12
,10
,08
,06
,04
,02
R=VL/ν=420000
Cr riferito alla
superficie della sezione
maestra della fusoliera
S=0,00675 m²
Cr riferito alla
superficie alare S=0,145 m²
-12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12α°

Fig. 26.

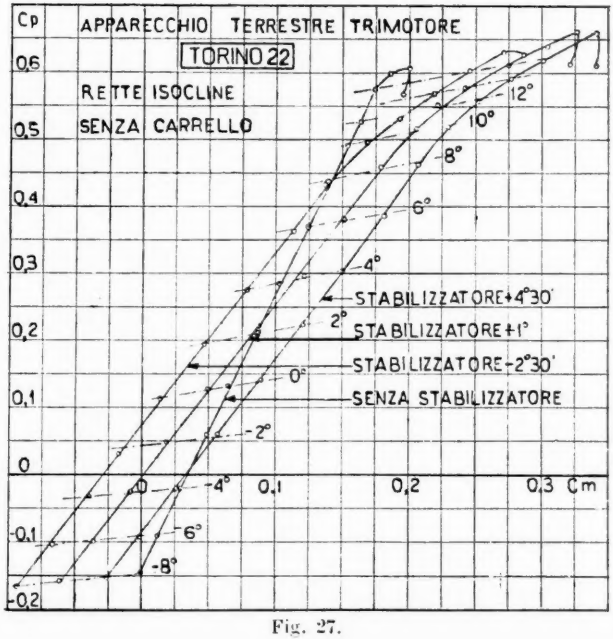

Cp
APPARECCHIO TERRESTRE TRIMOTORE
TORINO 22
RETTE ISOCLINE
SENZA CARRELLO
0,6
0,5
0,4
0,3
0,2
0,1
0
-0,1
-0,2
12°
10°
8°
6°
4°
2°
0°
-2°
-4°
-6°
-8°
STABILIZZATORE+4°30'
STABILIZZATORE+1°
STABILIZZATORE-2°30'
SENZA STABILIZZATORE
0,1
0,2
0,3 Cm

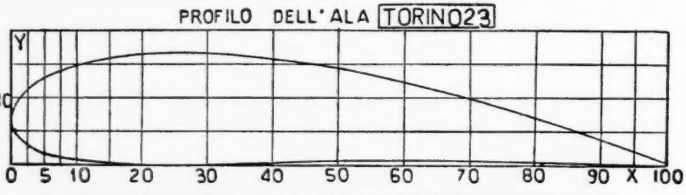
Fig. 27.

end sections trapezoidal in plan. The tests were carried out with four different conditions:—

(*a*) Wing alone with and without power eggs (Fig. 23).
(*b*) Fuselage alone (Fig. 26).
(*c*) Aeroplane without tail surfaces or undercarriage (Fig. 27).
(*d*) Aeroplane with horizontal tail surface and three control angles ($4° 30'$; $1°$; $-2° 30'$) both with and without undercarriage. (Figs. 24, 25, 27).

The presence of the power eggs considerably increases the minimum drag of the wing $c_{r\,min}$ which increases from 0.0065 to 0.01, that is an increase of nearly 54 per cent. The increase in drag set up by the power eggs, in absolute value, increases with the angle of incidence so that with $\alpha = 16$ degrees, to which corresponds $c_p = 0.63$, Δc_r is equal to 0.014.

The slope c'_p of the curve (c_p, α) is also slightly decreased, from 2.21 to 2.1, so that the overall effect of the power eggs may be reduced to an increase of minimum drag and a decrease of the effective aspect ratio. The maximum efficiency decreases in corresponding degree from 20.8 to 17.4.



X	0	2,5	5	7,5	10	15	20	30	40	50	60	70	80	90	95	100
Ys	6,5	11,2	12,9	14,2	14,9	16,0	16,6	16,6	16,0	14,5	12,5	10,2	7,35	4,0	2,2	0,3
Yi	6,5	2,7	1,66	1,16	0,79	0,4	0,16	0	0,25	0,4	0,5	0,5	0,4	0,3	0,2	0

Fig. 28.

The curve of the lift coefficients as a function of the c_m reveals that the focus is located always at about 0.25 of the mean chord, the interference of the power eggs being manifested only as a marked increase of the coefficient of focal moment c_{mf} which from the value 0.035 increases to 0.085.

The drag coefficient c_r of the fuselage alone, referred to the greatest cross-section of the fuselage, is 0.05 and referred to the wing area 0.0025, or roughly 38 per cent. of the drag coefficient of the wing. The total $c_{r\,min}$ of the aeroplane with undercarriage is 0.02, and that of the aeroplane without undercarriage is 0.013, the total drag being thus made up as shown in the following table:—

Wing	32.5 per cent.
Power eggs	17.5 ,, ,,
Fuselage	12.5 ,, ,,
Tail unit	2.5 ,, ,,
Undercarriage	35 ,, ,,
	100 per cent. = 0.02

Fig. 27 shows the curves giving the lift coefficients c_p as a function of the moment coefficients for the aeroplane with the horizontal tail surface with the three angles mentioned above, and for the aeroplane without horizontal tail surfaces. In the graph, with incidence graduation, Crocco's " isoclines "* are

* Crocco, " Elementi di aviazione."

drawn. These, considering the isoclines $-2°$ and $+6°$, show that the Δc_m due to the horizontal tail surface changes from -0.025 to $+0.025$, the lift coefficient c_{pe} of the horizontal tail surface undergoing the corresponding change from -0.0625 to $+0.0625$, since the volumetric wing/horizontal tail surface ratio $(S_a L_a)/(S_p L_p) = 2.5$.

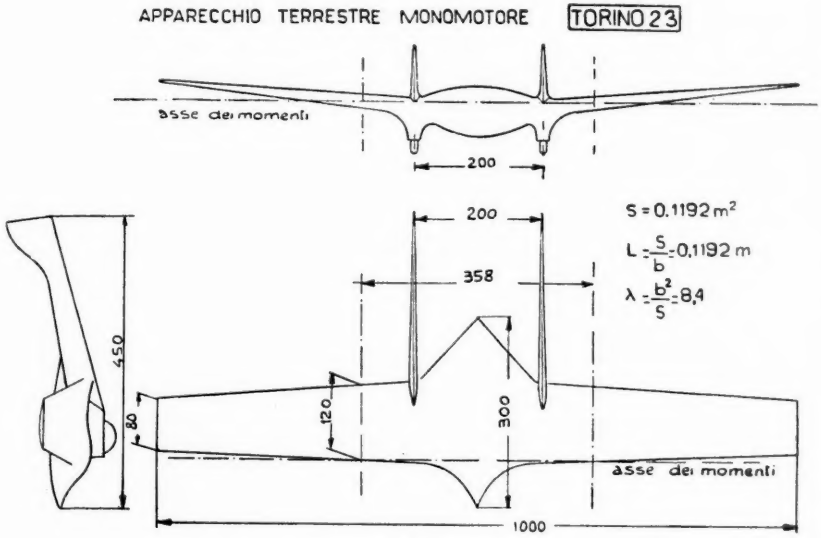


Fig 29.

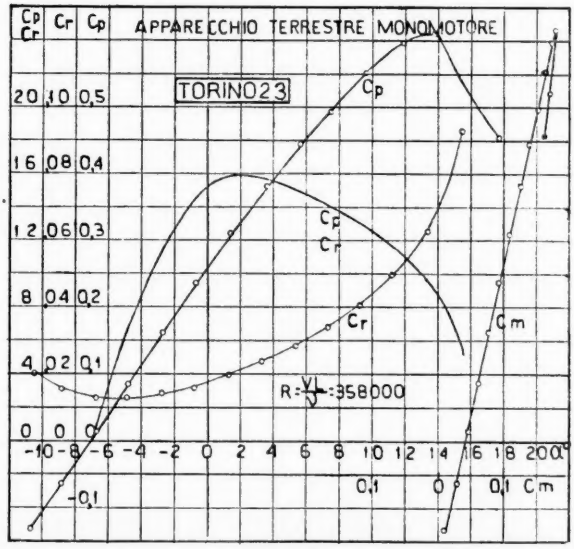
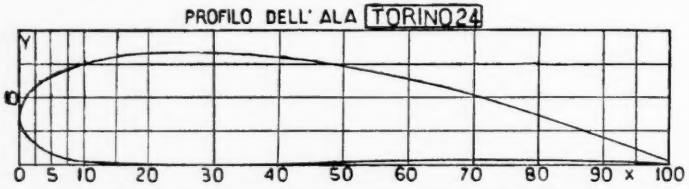


Fig. 30.

It follows that $dc_{pc}/d\alpha = 0.9$, hence the induction factor $\epsilon = 0.5$, the angular coefficient of lift of the tail with aspect ratio 3.8, being 1.8. The slope of the isoclines determined experimentally is 0.39, whilst the calculated slope, assuming the centre of pressure of the horizontal tail surface to be at 0.25 its chord from the leading edge and neglecting the focal moment, is 0.34.

" Torino 23 " (Figs. 28, 29, 30)

This is a landplane with single engine. The cantilever wing is very thick at the centre section as it incorporates the fuselage. In plan the wing is made up of two trapezoidal end sections connected to a rhomboidal centre section. The object of this plan form is to ensure inherent stability without having recourse to horizontal tail surfaces which are entirely absent in this model. The undercarriage wheels, which have a wide track, are almost completely hidden, together with their struts, within two large fairings carried by the wing. The wing also



X	0	2,5	5	7,5	10	15	20	30	40	50	60	70	80	90	95	100
Y_S	6,5	11,7	13,2	14,2	14,9	16,1	16,6	16,6	16,1	14,8	12,5	10,6	7,45	3,82	2,12	0,3
Y_I	6,5	2,58	1,60	0,85	0,4	0,2	0,1	0	0,1	0,2	0,3	0,43	0,5	0,4	0,3	0

Fig. 31.

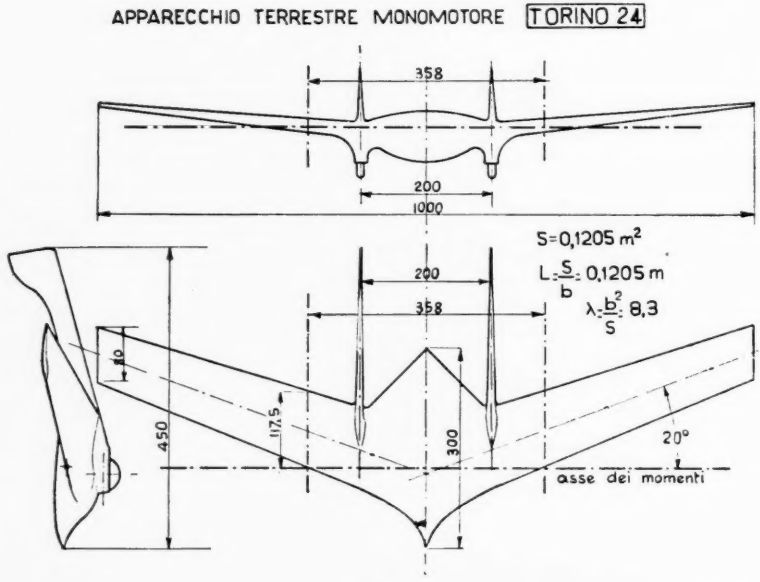


Fig. 32.

bears the vertical tail surfaces through the medium of two tail booms. The chief results are as follows:—

$$(c_r)_{min} = 0.0125\,;\ (c_p/c_r)_{max} = 16\,;\ c_{p\ max} = 0.61.$$

The focus is at 0.25 of the reference chord from the axis of the moments shown in Fig. 29. The coefficient of focal moment is 0.04.

" Torino 24 " (Figs. 31, 32, 33)

This is a landplane with single engine, derived directly from the " Torino 23." The wing is almost the same both as regards dimensions and section as that of the " Torino 23," with the essential difference, however, of the sharp sweep back of the two end sections of the wing as shown in Fig. 32. As regards the results the " Torino 24 " differs from the " Torino 23 " chiefly by the notable decrease of the $c_{p\ max}$, which from the value of 0.61 for the " Torino 23 " drops to 0.565, and by the displacement of the focus which from a position 0.25 of the mean chord recedes to 0.40.

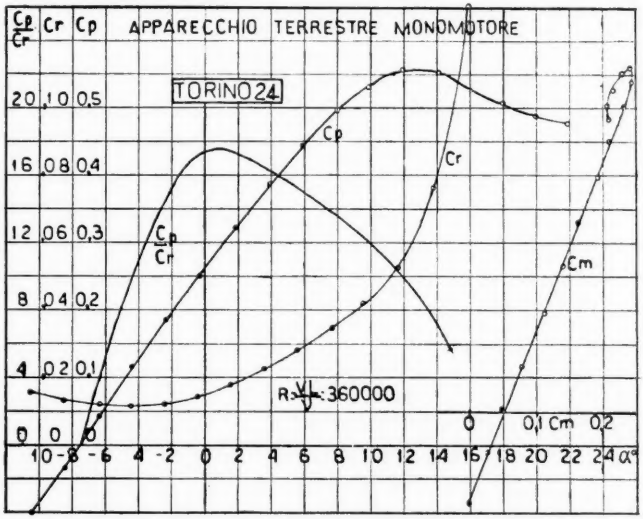
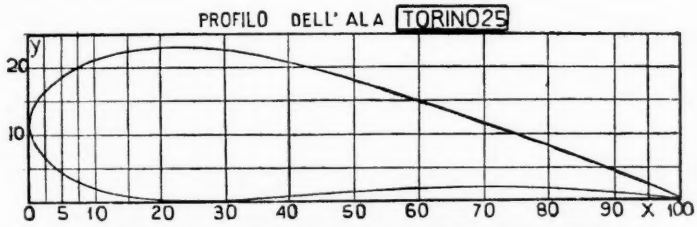


Fig. 33.



X	0	2.5	5	7.5	10	15	20	30	40	50	60	70	80	90	95	100
Ys	11	16,2	18,3	19	21	22,5	23	22,8	21	18,1	15,1	11,8	8,3	4,5	2,7	0,2
Yi	11	6,65	4,5	3,15	2,1	0,8	0,3	0,3	0,85	1,4	2	2,17	2	1,45	0,7	0

Fig. 34.

"Torino 25" (Figs. 34, 35, 36)

This is a "soaring" aeroplane. The wing end sections have a considerable taper, and are swept back for inherent stability. The wing centre section is extremely thick as it incorporates the fuselage. The chief aerodynamic characteristics are:—

$$(c_r)_{min} = 0.012\ ;\ (c_p)_{max} = 0.675\ ;\ c_p/c_r = 19.2\ ;$$

focus at 0.45 of the mean chord, coefficient of focal moment of wing = 0.

The high value of the efficiency is a result of the high aspect ratio ($\lambda = 12$).

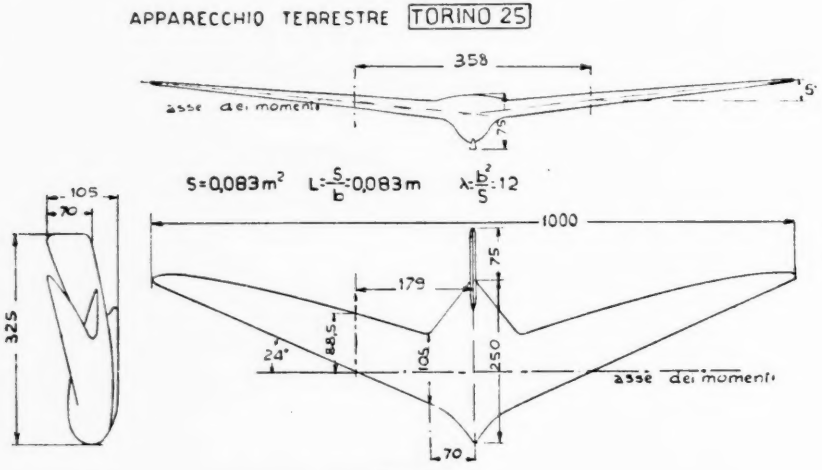


Fig. 35.

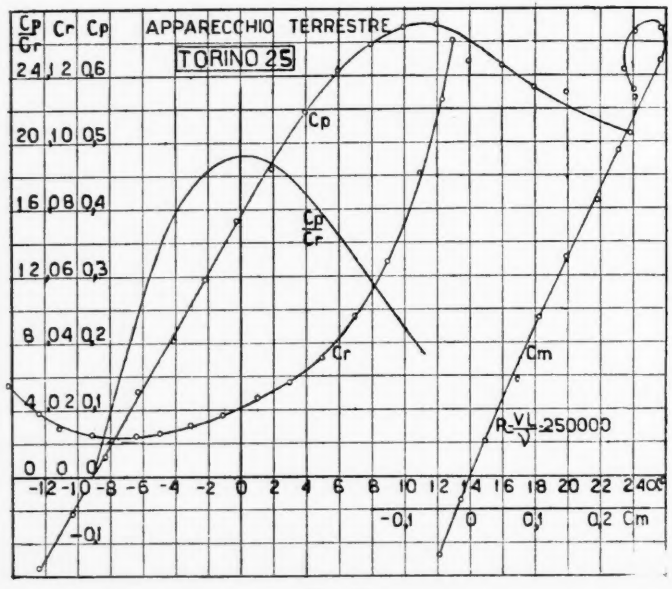
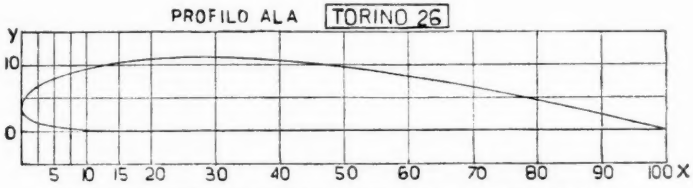


Fig. 36.

" TORINO 26 " (Figs. 37, 38, 39)

This is a sail plane. Unlike the " Torino 25 " it has a very low aspect ratio (1.94) of the wing which is triangular in plan. As consequences of the low aspect ratio are the low efficiency $(c_p/c_r)_{max} = 11$, and the fact that the peak of the lift curve does not occur before incidence 28°. It is interesting to note that despite the low aspect ratio the discrepancies between the results deduced



X	0	2,5	5	7,5	10	15	20	30	40	50	60	70	80	90	95	100
Y	3,82	6,58	7,81	8,67	9,25	10,2	10,8	11,15	10,68	9,56	8,26	6,58	4,63	2,58	1,47	0,2
Y	3,82	1,29	0,71	0,45	0,31	0,13	0	0	0	0	0	0	0	0	0	0

Fig. 37.

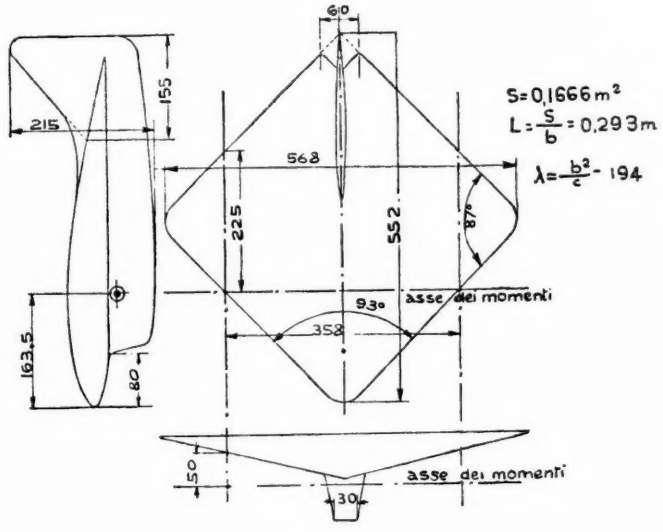


Fig. 38.

from theory, reducing the wing area to a single vortex filament support of the free vortex coil, and the test results are in fairly close agreement. Thus it is known, for instance, that the coefficient of induced drag for a wing with end sections triangular in plan, is given by

$$c_{ri} = (1 + \delta)\ (2/\pi\lambda)\ c_p^2$$

in which δ is a constant which decreases in value as λ decreases. For the value of λ corresponding to that of the machine under consideration, one can assume with fair approximation that $\delta = 0$.

Hence the efficiency may be deduced:—

$$e = c_p / c_r = c_p / \{ c_{ro} (2/\pi\lambda) c^2{}_p \} = c_p / (0.0075 + 0.328\, c^2{}_p)$$

which reaches highest value for the value of c_p given by $0.0075 = 0.328\, c_p{}^2$, whence $c_p = 0.151$. For this lift value we have $c_{ri} = 0.0075$ and $c_r = 0.015$, hence an efficiency $e = 10$. The experimental graph gives maximum e as occurring at $c_p = 0.149$ and $e_{max} = 11$, proving the good agreement.

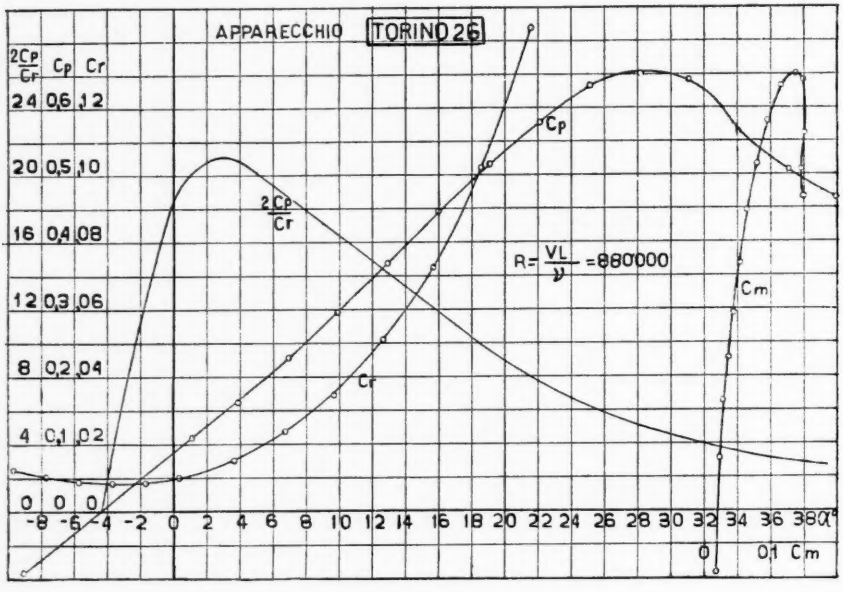
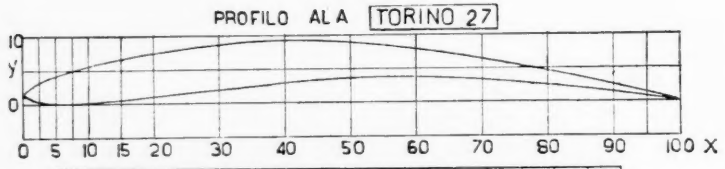


Fig. 39.



X	0	2,5	5	7,5	10	15	20	30	40	50	60	70	80	90	95	100
Y	1,2	3,12	4,10	4,9	5,5	6,62	7,5	8,6	9,13	8,95	8,04	6,62	4,83	2,6	1,43	0
Y	1,2	0,2	0	0,2	0,33	0,65	1,22	2,14	3,03	3,72	3,93	3,72	2,85	1,61	0,9	0

Fig. 40.

It is also known that for a wing with plan form like that of the wing under consideration the angular lift coefficient is defined by

$$c'_p = c'_{p\infty} / \{ 1 + (1+\tau)\, (2/\pi\lambda)\, c'_{p\infty} \}$$

in which $c'_{p\infty}$ is the angular lift coefficient for infinite span, and τ is a constant

the value of which decreases with increasing λ. For $\lambda = 1.94$ one may assume* $\tau = 0.6$ and hence for $c'_{p\infty} = 3$, we get:—

$$c'_p = 3/\{1 + 1.6\,(6/\pi\ 1.94)\} = 1.17.$$

The value obtained from the tests is $c'_p = 1.14$.

" TORINO 27 " (Figs. 40, 41, 42)

This like the " Torino 26 " is a sail plane with wing of low aspect ratio. It differs from the " Torino 26 " by a small difference in the plan form, as seen from Figs. 38, 41, and by the wing section which is considerably more highly cambered. As a consequence of the low value of λ ($\lambda = 2$) are the fact, as in

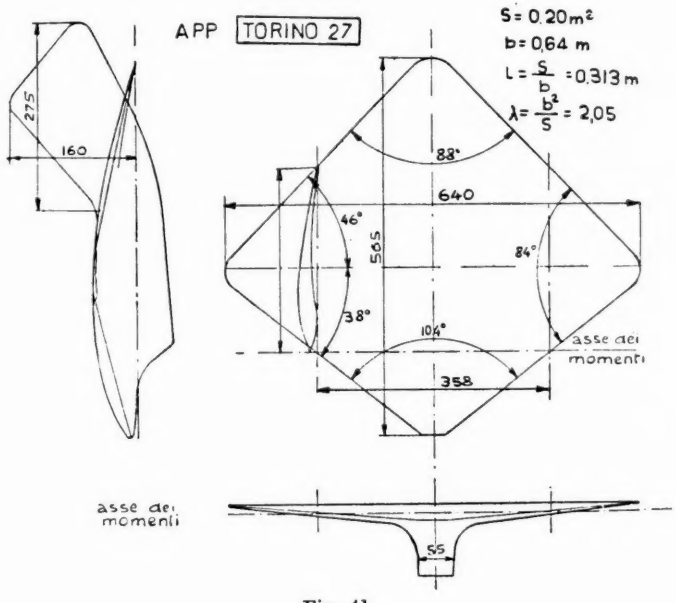


Fig. 41.

the " Torino 26 " model, that the peak of the lift curve does not occur before angle of incidence 28°, and the low maximum efficiency, which is 11. In the case of this model, also, the values obtained from theory show good agreement with the values established by the tests, as the following table proves:—

c_p for $(c_p/c_r)_{max}$ calculated	c_p for $(c_p/c_r)_{max}$ experimental	$(c_p/c_r)_{max}$ calculated	$(c_p/c_r)_{max}$ experimental	$d c_p/d\alpha$ calculated	$d c_p/d\alpha$ experimental
0.168	0.165	9.35	11.4	1.19	1.28

The $c_{p\ max}$ of the " Torino 27 " is somewhat higher than that corresponding to the " Torino 26," a result of the higher camber of the section: $c_{p\ max} = 0.77$ as against $c_{p\ max} = 0.66$ for the " Torino 26."

* See, for instance, SCHEPISI, " Sulla forma in pianta dell'ala." L'Aerotecnica, 1923, No. V.

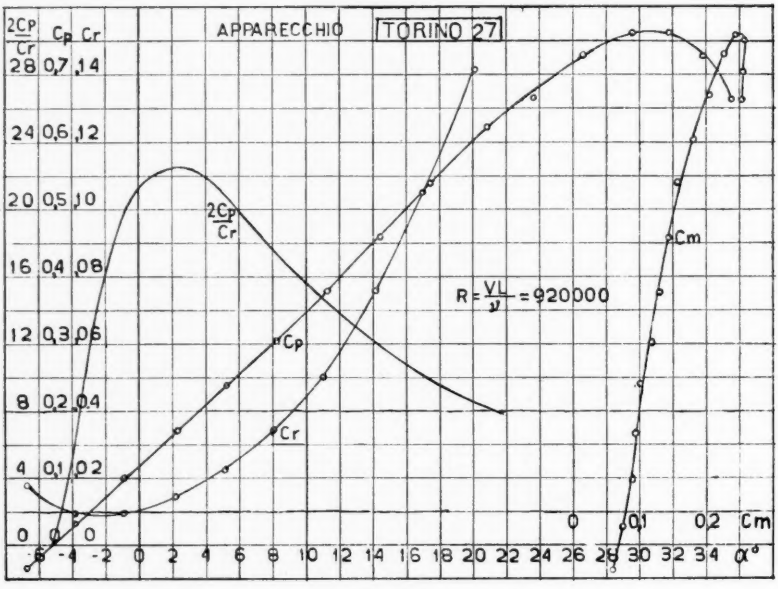
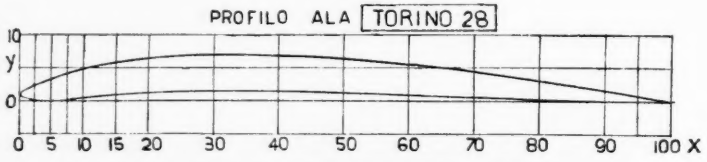


Fig. 42.

" Torino 28 " (Figs. 43, 44, 45)

This again like the two preceding machines is a sailplane, with wing triangular in plan and low aspect ratio. It differs from the " Torino 26 " and " Torino 27 " in that it has an orthodox fuselage connected to the wing by stays and to the undercarriage by struts. These and the wheels are covered in by a fairing.



X	0	2,5	5	7,5	10	15	20	30	40	50	60	70	80	90	95	100
Y	0,75	2,45	3,52	4,15	4,80	5,90	6,60	7,05	7,05	6,42	5,60	4,50	3,26	1,87	1,04	0,2
Y	0,75	0	0,16	0,33	0,5	1,0	1,41	1,5	1,05	1,08	0,75	0,41	0,26	0,1	0	0

Fig. 43.

The minimum drag is only slightly higher than that of the " Torino 27," $(c_r)_{min}=0.012$, the maximum efficiency being consequently lower: $(c_p/c_r)_{max}=9$. The curves of the drag and lift coefficients show the same characteristics as those for the two preceding models.

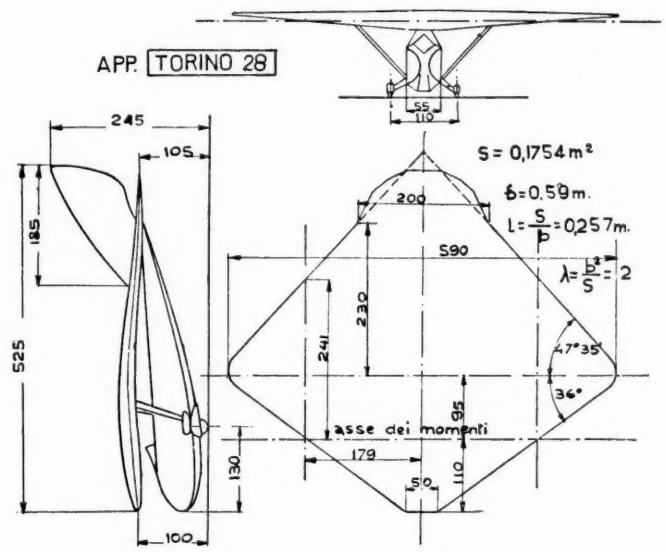


Fig. 44.

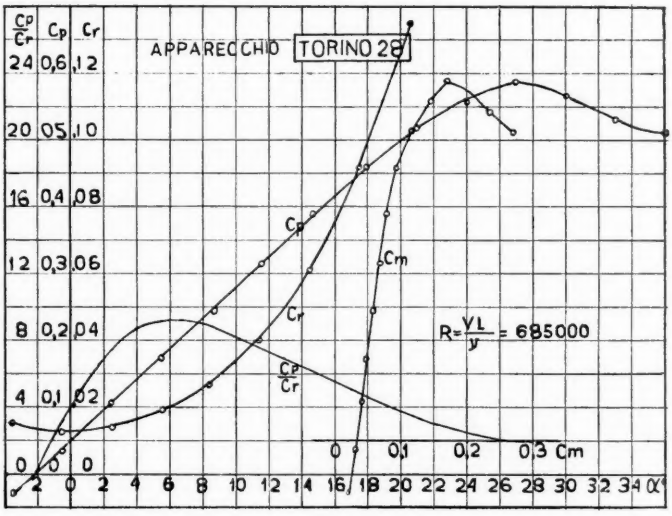
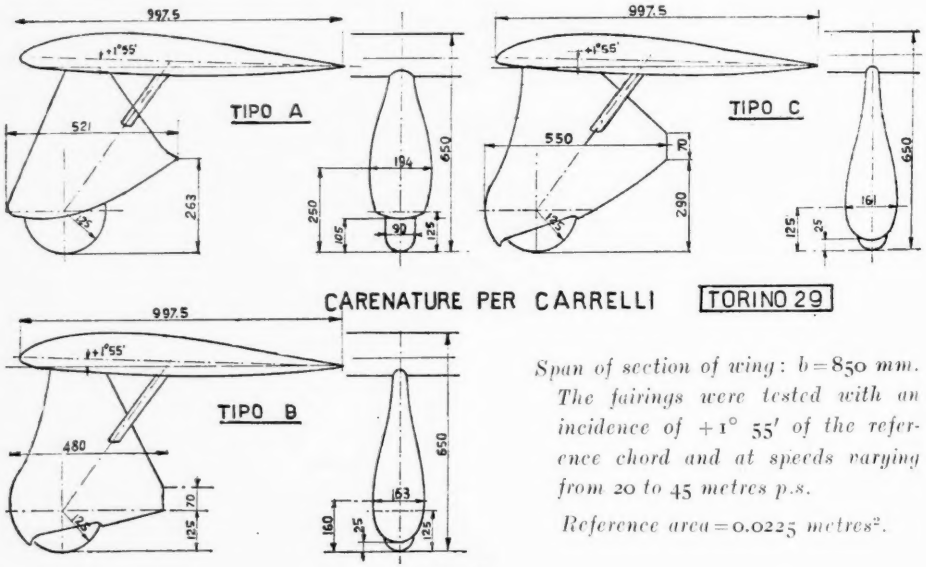


Fig. 45.

" Torino 29 " (Figs. 46, 47, 48)

The designation " Torino 29 " covers a variety of undercarriage models with different fairing design. The designs submitted to tests are shown in Fig. 46. In order to enable determination with sufficient approximation of the drag characteristics of the various undercarriages large scale models were used for the tests,

and each undercarriage was tested with a section of the appropriate wing, so as to enable consideration of the effect of wing interference. Having determined the type of undercarriage fairing giving minimum drag, tests were executed on this model to determine the drag of the wing undercarriage assembly as well as that of the wing alone, the wing in presence of the undercarriage, and the undercarriage alone, so that the various interference effects could be analysed. The results of the tests are shown in Figs. 47, 48, in which the drag coefficient values referred to the maximum cross-section of the wheel, are shown as function of the speed.



Span of section of wing: $b = 850$ *mm.*
The fairings were tested with an incidence of $+1°\ 55'$ *of the reference chord and at speeds varying from 20 to 45 metres p.s.*
Reference area $= 0.0225$ *metres*^{2}.

Fig. 46.

The " optimum " undercarriage amongst those tested, denoted in the graphs as " type *C*," has the smallest area projected in the direction of motion and the greatest length in the direction of the flow. Moreover the wheel is almost completely enclosed in the fairing. The drag coefficient of undercarriage *C* alone, at the highest speeds of the tests is $c_r = 0.19$. The presence of the wing increases c_r to 0.265, that is an increase of 39 per cent. on the initial drag. As the c_r of an ordinary undercarriage without fairing and for a single wheel may be assumed to be 0.5, it can be concluded that a good fairing is able to reduce the drag of an undercarriage by 47 per cent.

The drag coefficient of type *A* is 0.43, and that of type *B* 0.3, these values constituting increases relative to the c_r of *C* of 81 and 13 per cent. respectively.

The curves of Fig. 47 show that at the maximum speed used in the tests (44 metres per second—144 feet per second) a scale effect, small but appreciable, is still manifested despite the large dimensions of the model.

The " optimum " type *C* undercarriage, in addition to the drag tests, was also subjected to tests in a side wind, the wing not being present, and the corresponding curves are reproduced in Fig. 48. From these it can be seen that the drag coefficient increases with the angle of the side wind, or lateral force,

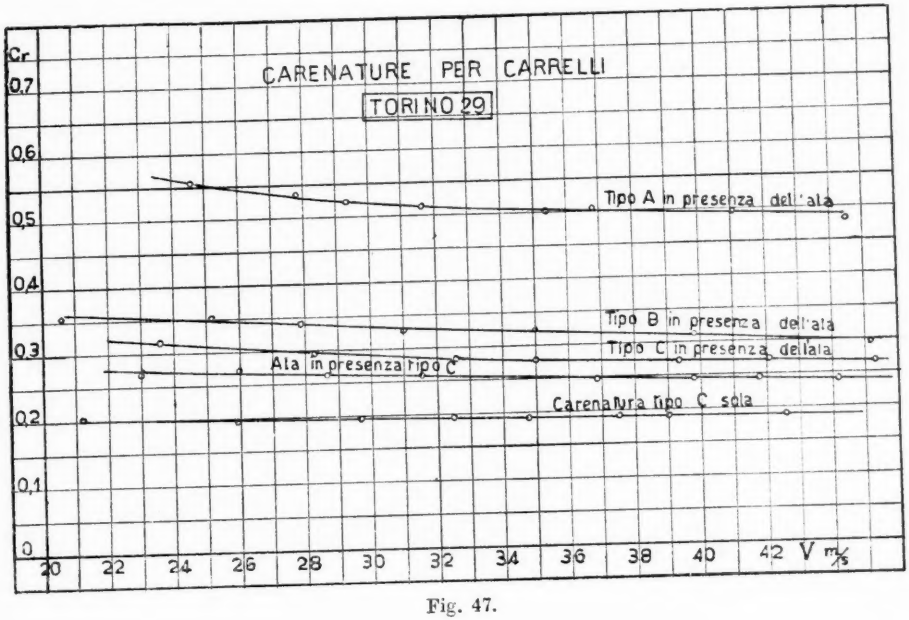

Cr
CARENATURE PER CARRELLI
TORINO 29
Tipo A in presenza dell'ala
Tipo B in presenza dell'ala
Tipo C in presenza dell'ala
Ala in presenza tipo C
Carenatura tipo C sola
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
20 22 24 26 28 30 32 34 36 38 40 42 V m/s

Fig. 47.

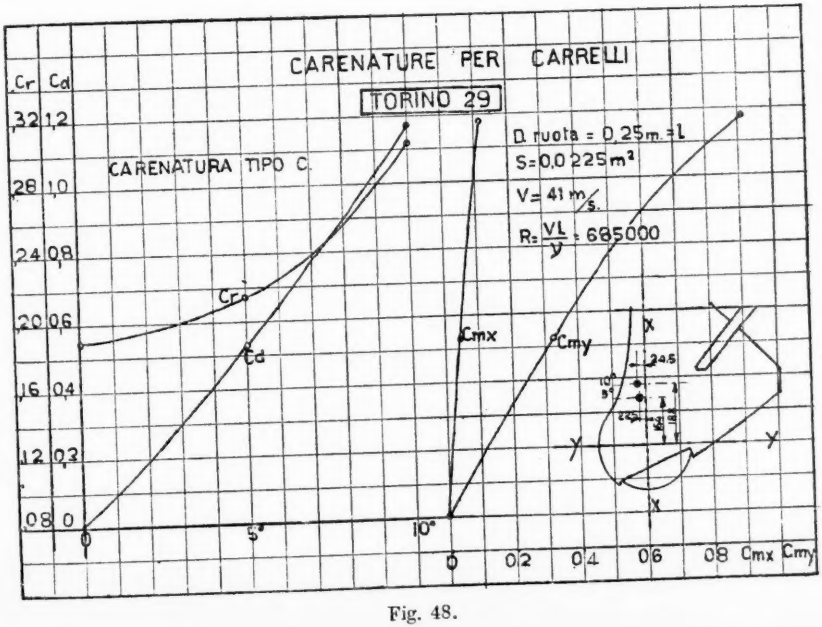
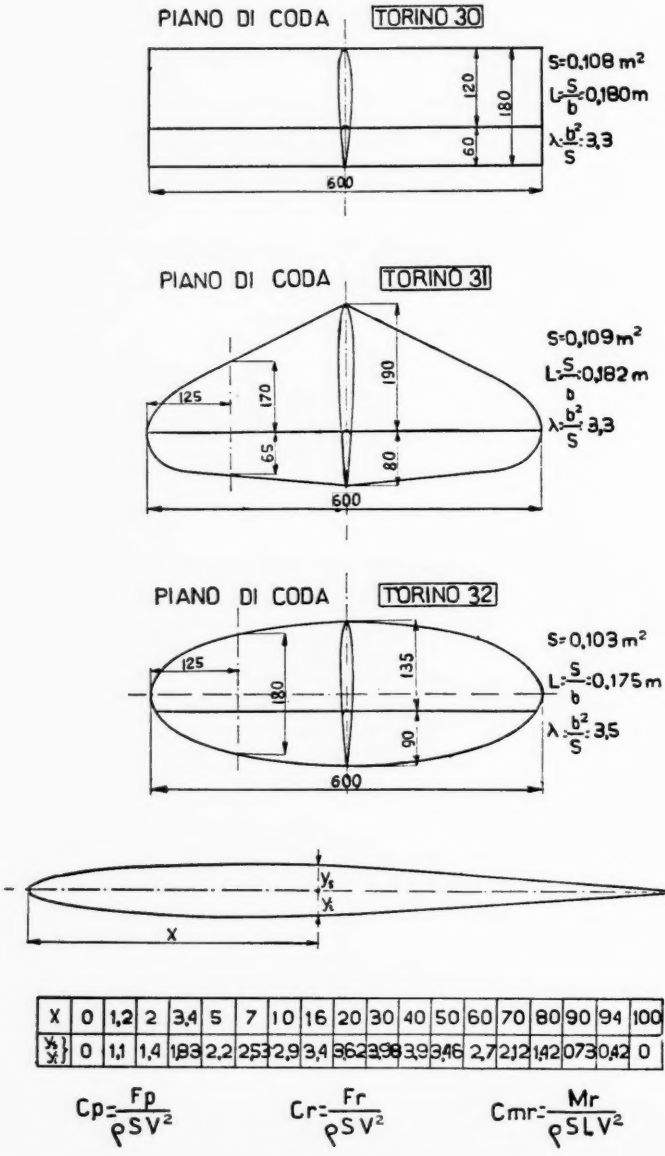

CARENATURE PER CARRELLI
TORINO 29
Cr Cd
CARENATURA TIPO C
D ruota = 0,25m = l
S=0,0225m²
V= 41 m/s
R= Vl/ν = 685000
Cr
Cd
Cmx
Cmy
0 5° 10°
0 02 04 06 08 Cmx Cmy

Fig. 48.

according to a law approximately parabolic, which may be expressed by the formula

$$c_r = 0.19 + 0.082\ c_p^2$$

whilst the lateral force coefficient c_d may be considered as a linear function of δ defined by $c_d = 6.75\ \delta$ (δ expressed in radians).



x	0	1,2	2	3,4	5	7	10	16	20	30	40	50	60	70	80	90	94	100
$\frac{y_s}{y_i}$	0	1,1	1,4	1,83	2,2	2,53	2,9	3,4	3,62	3,98	3,93	3,46	2,7	2,12	1,42	0,73	0,42	0

$$Cp = \frac{Fp}{\rho S V^2} \qquad Cr = \frac{Fr}{\rho S V^2} \qquad Cmr = \frac{Mr}{\rho S L V^2}$$

Fig. 49.

The run of the curve of the moments about the x and y axes, reproduced in Fig. 48, and having the origin in the trace of the wheel axis, is practically rectilinear, at any rate for angles of side wind not exceeding 8 to 10 degrees. Using these results of the tests in a side wind, the positions of the corresponding " centres of side wind pressure " were determined. These are shown also in

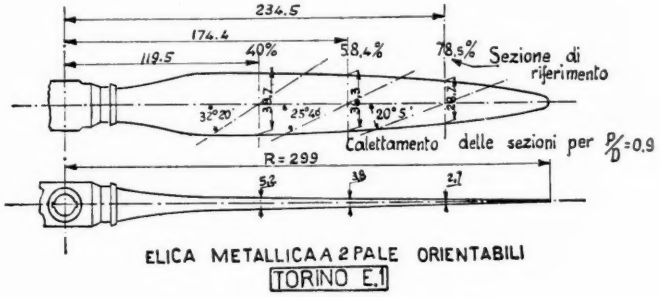


Fig. 50.

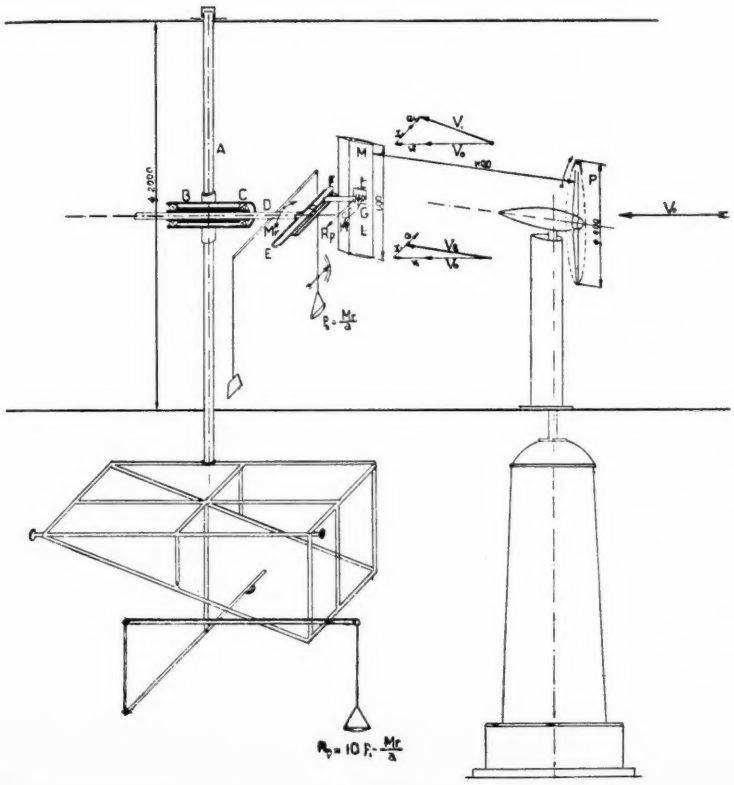


Fig. 51.

Fig. 48, from which it is seen how the point of application of the lateral force on the undercarriage is moved forwards, with respect to the direction of motion, of the wheel axis by about 0.9 D (diameter of the wheel), and upwards by about 0.70 D as a mean.

" Torino 30, 31, 32 " and " Torino E1 " (Figs. 49 to 68)

The models bearing the designation " Torino 30, 31, 32," are horizontal tail surfaces in plan respectively rectangular, triangular and elliptical, all with the same section shown in Fig. 49. The geometrical characteristics of the airscrew " Torino E1 " are shown in Fig. 50. The tests carried out on these models were undertaken at the instigation of S.E. General Crocco, at the request of the Air Ministry, with the object of determining the influence of the running airscrew on the aerodynamic characteristics of the horizontal tail surfaces. The results set out are those of a first series of tests carried out with no wing present

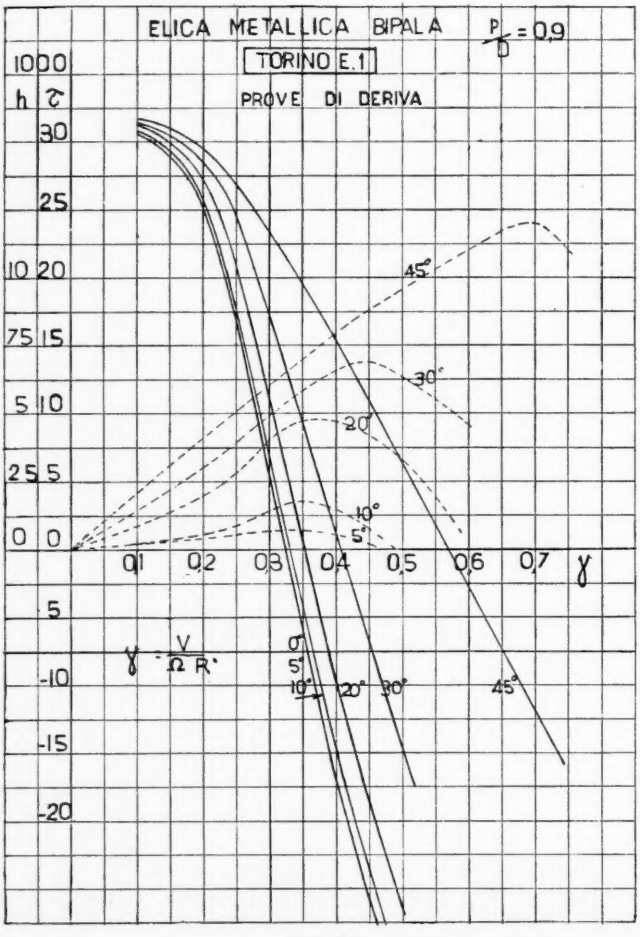


Fig. 52.

and without variation of the distance between the plane of the airscrew disc and the tail plane. The further tests, at present in course, will have as their object to study the difference in the interference effect on the tail arising either from the interposition of a wing at various positions between the airscrew and tail, or from variation of the distance between airscrew and tail.

The arrangement used for the tests is shown in Fig. 51.

The airscrew with diameter D of 600 mm., which is also the span of the horizontal tail surfaces tested and with pitch $p = 540$ mm., measured at $0.785\ R$, is carried and controlled by the airscrew balance, described in the Series I reports, which enables the airscrew to be set at any angle of incidence α relative to the direction of the airstream. The horizontal tail surface is carried on a rigid rod by the universal balance with three fulcrums described by the Director of the Laboratory, Professor Panetti, in an article on the Laboratory in the "Giornale della Associazione Nazionale degli Ingegneri Italiani," 1920. The horizontal tail surface is arranged with its plane of symmetry horizontal (hence span vertical). In order to allow the relative position of the tail with respect to the airscrew

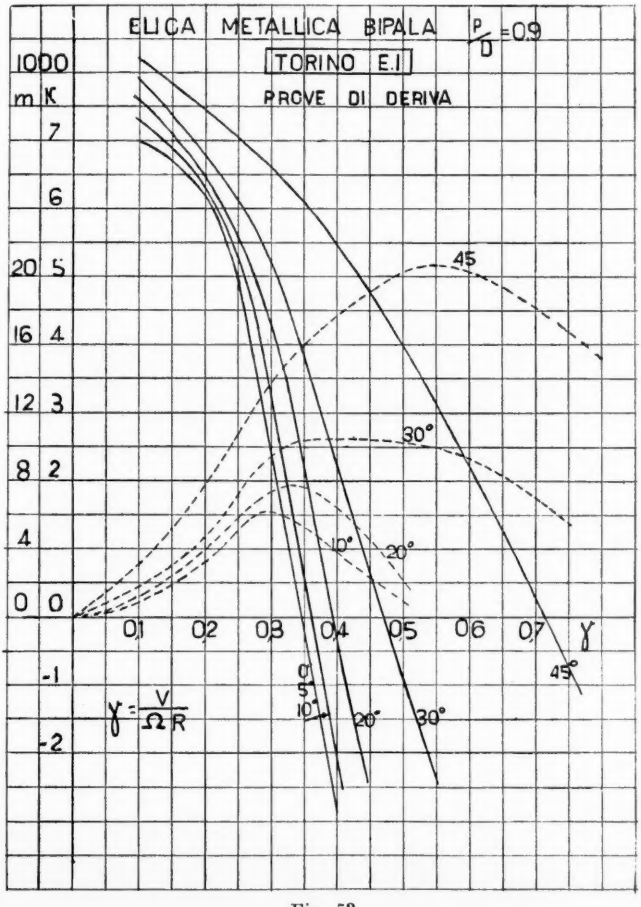


Fig. 53.

to remain unvaried irrespective of the incidence, and in order to enable measurement of the rolling moment induced by the action of the airscrew on the horizontal tail surface, the latter was suspended in the wind tunnel in the following manner:—The vertical arm A of the balance, or arm transmitting to the balance the air forces acting on the model, carries a horizontal sleeve B which forms the support for a horizontal tube C, mounted in ball bearings, within which a shaft D is so mounted as to be capable of sliding motion within C. D bears at its other end a horizontal tube E, normal to D and slotted along one generator. A small bar F can be slipped along E, so that bar F can be set at any horizontal distance from the tunnel axis. The bar F is provided with a circular slit with vertical axis within which engages a similar circular quadrant H to which the

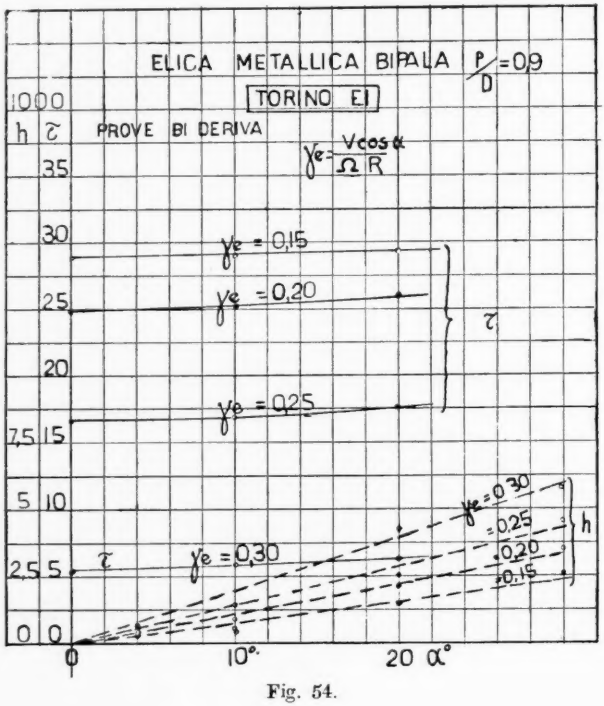


Fig. 54.

model is rigidly connected. By combining rotation about the vertical axis L with horizontal displacements along E and along D, the displacement of the horizontal tail surface may be reduced to rotation about the vertical axis K, which is the axis about which the airscrew is rotated in order to impart to it the desired incidence α. Suitable compression and locking screws enable the model to be secured once the change of position has been effected.

The tests were carried out on the three horizontal tail surfaces shown in Fig. 49 with control angle 0°, the tests being extended to include a control angle of 15° only in the case of the rectangular surface. For every incidence α the lift and rolling moment of the tail were measured and also the airscrew coeffi-

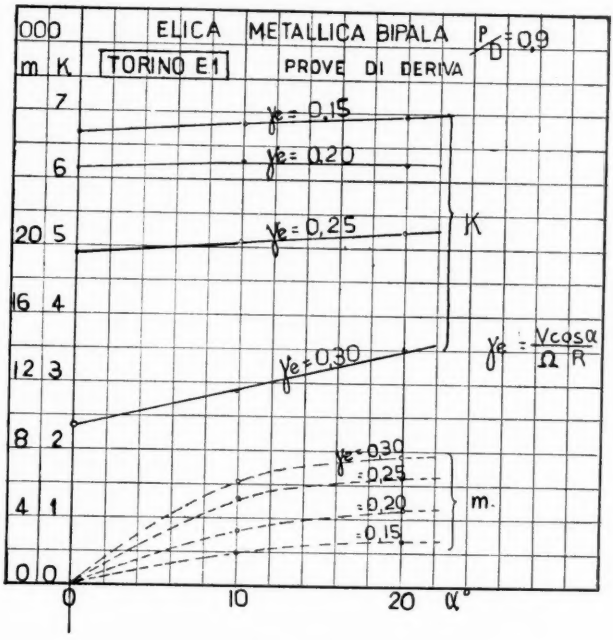

000
m K
ELICA METALLICA BIPALA P/D = 0,9
TORINO E1
PROVE DI DERIVA
7
6
20 5
16 4
12 3
8 2
4 1
0 0
γe = 0,15
γe = 0,20
γe = 0,25
γe = 0,30
K
γe = Vcosα / ΩR
γe = 0,30
= 0,25
= 0,20
= 0,15
m.
0
10
20
α°

Fig. 55.

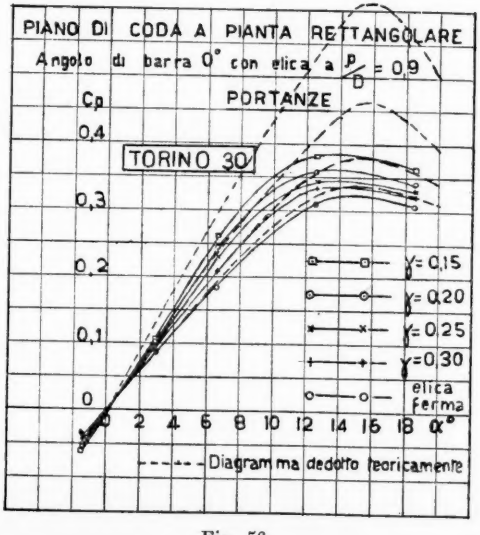

PIANO DI CODA A PIANTA RETTANGOLARE
Angolo di barra 0° con elica a P/D = 0,9
Cp
PORTANZE
TORINO 30
0,4
0,3
0,2
0,1
0
γ = 0,15
γ = 0,20
γ = 0,25
γ = 0,30
elica ferma
0 2 4 6 8 10 12 14 16 18 α°
Diagramma dedotto teoricamente

Fig. 56.

cients of thrust, torque, lateral force, torque due to lateral force, and the measurements were effected for all the range of the advance/diameter ratios γ comprised between o and the higher experimental pitch of the airscrew. No attempt was made to measure the drag of the tail for, although as far as possible all air reactions on the suspension were eliminated by careful fairing, the reactions on the suspension were fairly heavy in comparison with the drag of the model, so

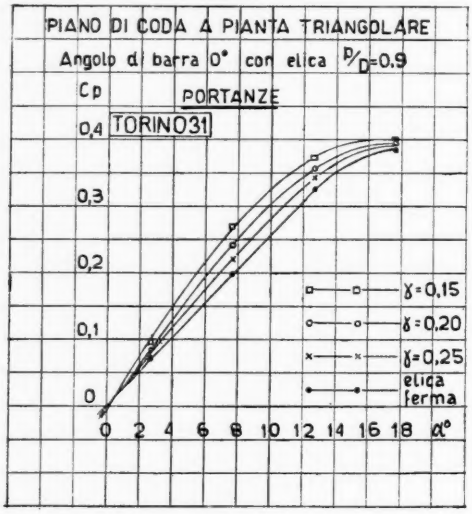


Fig 57.

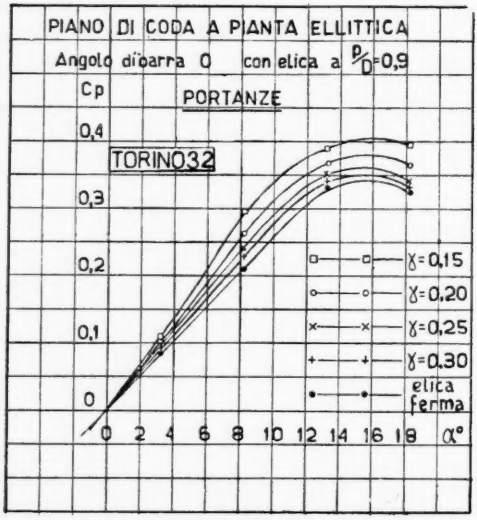


Fig. 58.

that measurements would not have given sufficient accuracy. The coefficients of thrust and torque of the airscrew at the various side wind angles were measured using the methods described by the Director of the Laboratory in the first Series of these Reports. The lift of the horizontal tail surface was measured using the three fulcrum balance with rigid arm shown in Fig. 51, whilst the rolling moments

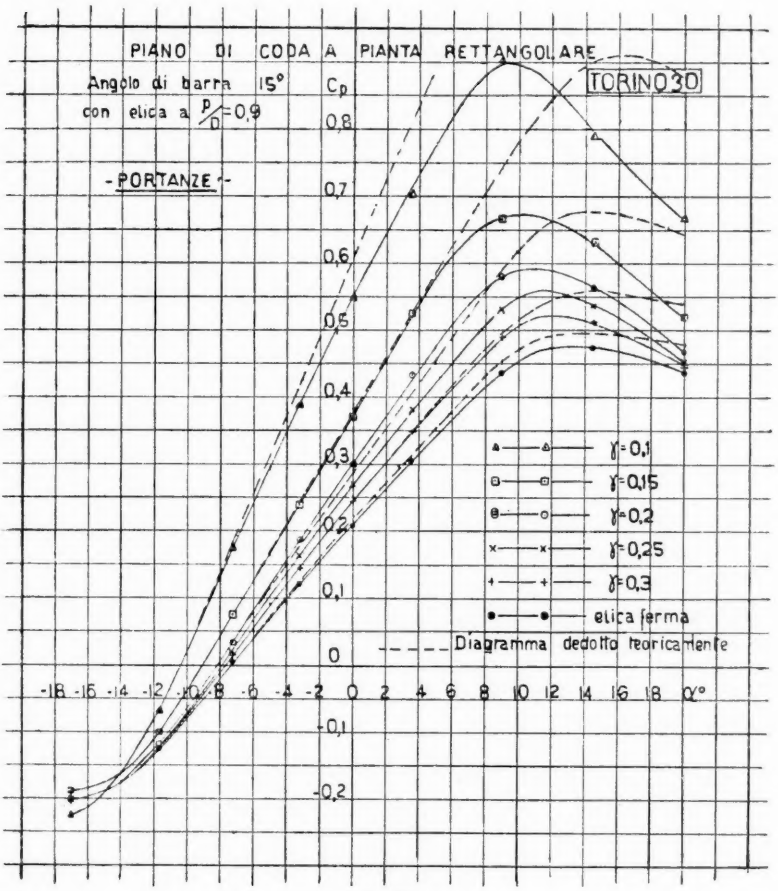


Fig. 59.

were measured using balances with wire suspension, this being permitted by the suspension system already described. The results of the tests are shown in Figs. 52, 53, 54, 55, as regards the airscrew, and in Figs. 56, 57, 58, 59, 63, 64, 65, 66, for the horizontal tail surfaces.

From the curves of Figs. 52, 53 it is seen that the effect of the incidence α is in the sense of an increase of the thrust coefficient τ and torque coefficient κ, but restricting consideration to incidences not exceeding 20° and referring these

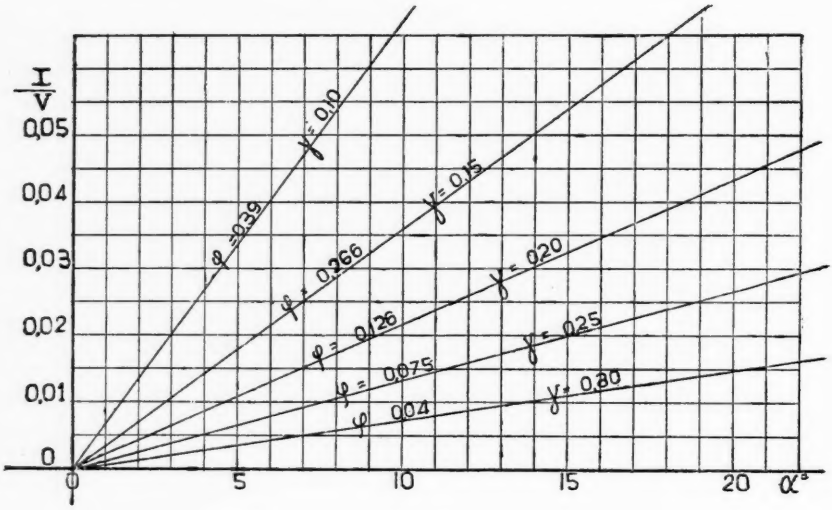

I/V
0,05
0,04
0,03
0,02
0,01
0
0
5
10
15
20
α°
γ = 0,10
γ = 0,15
γ = 020
γ = 025
γ = 0,30
φ = 0,39
φ = 0,266
φ = 0,126
φ = 0,075
φ 004

Fig. 60.

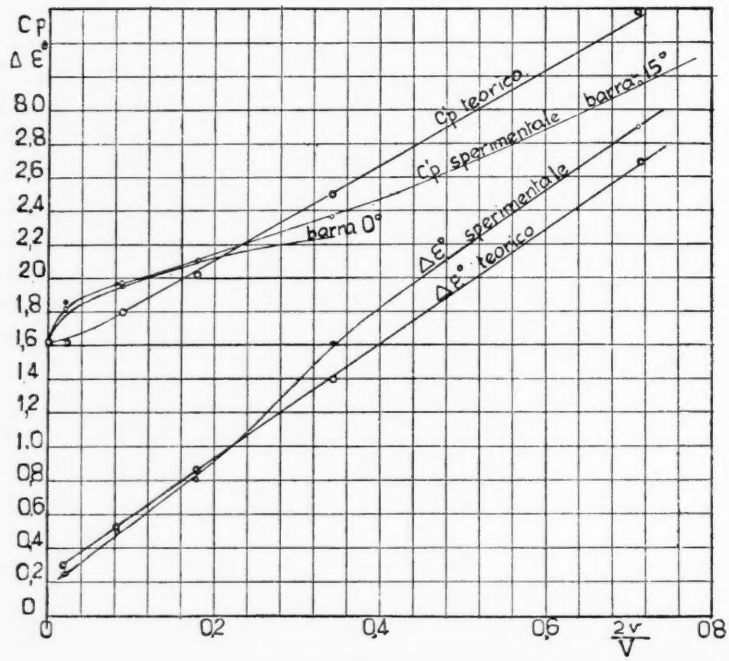

Cp
Δ E°
8,0
2,8
2,6
2,4
2,2
2,0
1,8
1,6
1,4
1,2
1.0
0,8
0,6
0,4
0,2
0
0
0,2
0,4
0,6
0,8
2v/V
Cp teorico.
Cp sperimentale barra 15°
barra 0°
ΔE° sperimentale
ΔE° teorico

Fig. 61.

same coefficients not to $V/\Omega R$ but to $V \cos \alpha/\Omega R$, these increases, as shown in Figs. 54, 55, are sufficiently small to be neglected, this being in complete agreement with expectation from theory. Thus, for instance, the increase of τ corresponding to $\alpha = 20°$ barely reaches 9 per cent. for $\gamma_e = 0.3$, and 3.8 per cent. for $\gamma_e = 0.2$, whilst the increase of κ is 6.1 per cent. for $\gamma_e = 0.25$. The curve of κ as a function of α for $\gamma_e = 0.3$ is the only one showing a slightly abnormal run.

The lateral force coefficients h vary for every γ_0 and in the above mentioned range of α values they vary in almost linear proportion with the incidence, as Fig. 54 shows, and the experimental angular coefficients $(\partial h/\partial \alpha)_{\gamma e = \text{const.}}$ agree fairly well with those yielded by the theory of the airscrew working in a side wind. According to this theory the coefficient of lateral force h^* may be written

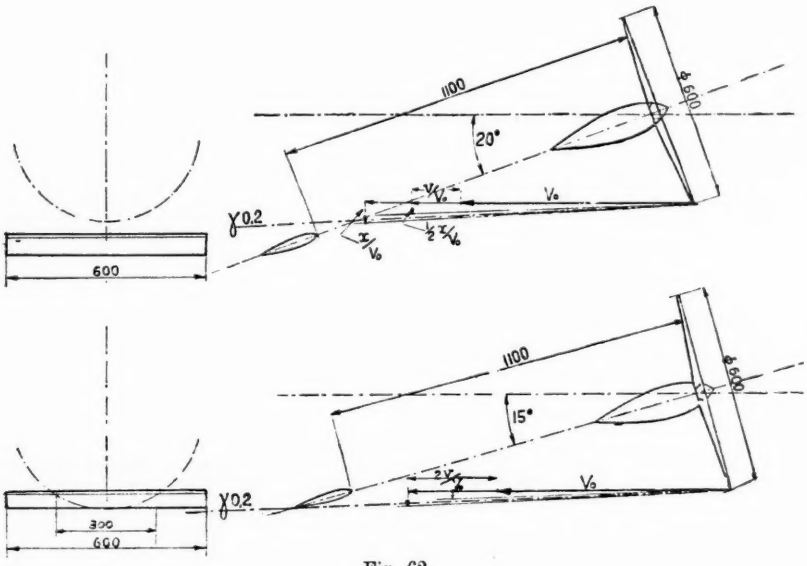


Fig. 62.

under the form $h = h_D (S/R^2)$, in which S is the total area of the blades of an airscrew of radius R, and h_D is given by :—

$$h_D = \tfrac{1}{2}\gamma_0 \left[\gamma_0 c'_\infty \zeta \phi_0 + c_0 (\psi_0 + \theta_1)\right] (\delta)$$

in which, in accordance with the usual notation adopted in Professor Pistolesi's theory of the mean velocity increases, we used :—

γ_0 for the effective advance/diameter ratio corresponding to the apparent advance/diameter ratio

$$\gamma = V/\Omega R \text{ ; that is } \gamma_0 = \gamma (1 + v/V)/(1 - \omega/\Omega)$$

since $\cos \alpha_e$ may be considered as equal to 1 ; and v and ω being the induced axial and rotational added velocities ;

c'_∞ for the angular coefficient of lift for infinite aspect ratio, which for the calculation we take as equal to 2.8 ;

ζ for the advance/diameter ratio corresponding to the experimental pitch of the airscrew ;

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* PISTOLESI, "Influsso di un vento laterale sul funziamento delle eliche." (L'Aerotecnica 1925.) Also PANETTI, "Corso di Costruzioni aeronautiche."

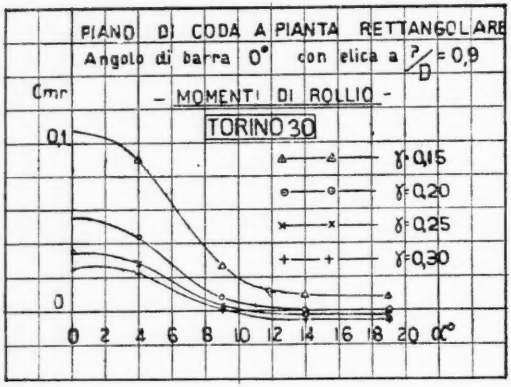


Fig. 63.

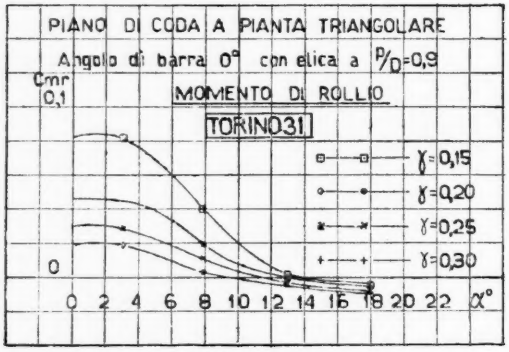


Fig. 64.

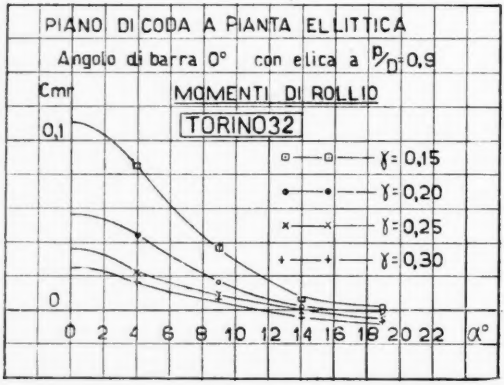


Fig. 65.

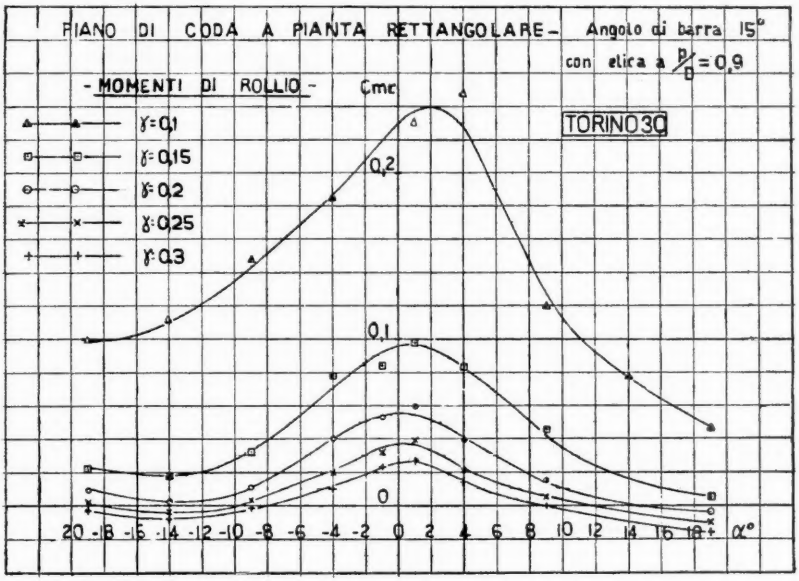

PIANO DI CODA A PIANTA RETTANGOLARE - Angolo di barra 15°
con elica a P/D = 0,9
- MOMENTI DI ROLLIO - Cmc
TORINO 30
γ=0,1
γ=0,15
γ=0,2
γ=0,25
γ=0,3
0,2
0,1
0
20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 α°

Fig. 66.

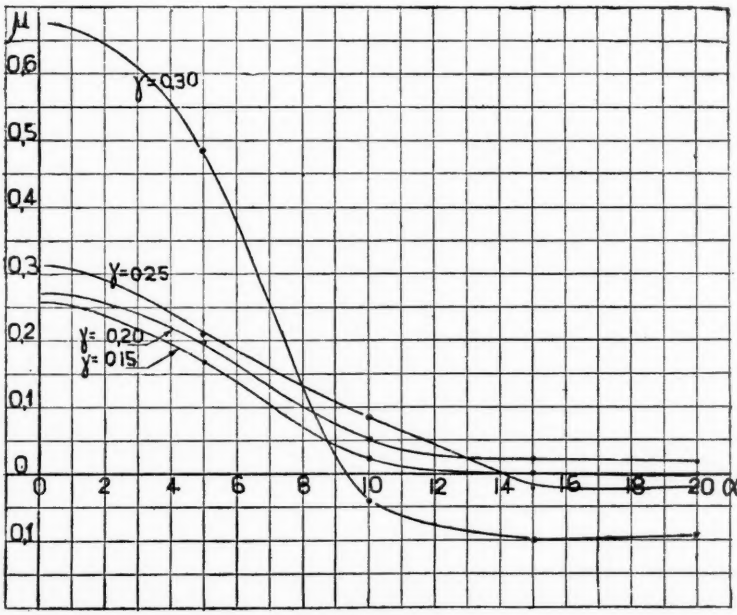

μ
0,6
0,5
0,4
0,3
0,2
0,1
0
0,1
γ=0,30
γ=0,25
γ= 0,20
γ= 0,15
0 2 4 6 8 10 12 14 16 18 20 α°

Fig. 67.

ϕ_0, ψ_0, θ_1, for the functions of ζ introduced by Professor Pistolesi in his above mentioned theory, the values of which corresponding to the various values of ζ have been tabulated in Pistolesi's "Una teoria semplificata per lo studio delle eliche" (Rendiconti Tecnici e Sperimentali di Aeronautica, 1923) and in Pistolesi's "Influsso di un vento laterale sul funzionamento delle eliche" (*L'Aerotecnica*, 1925).*

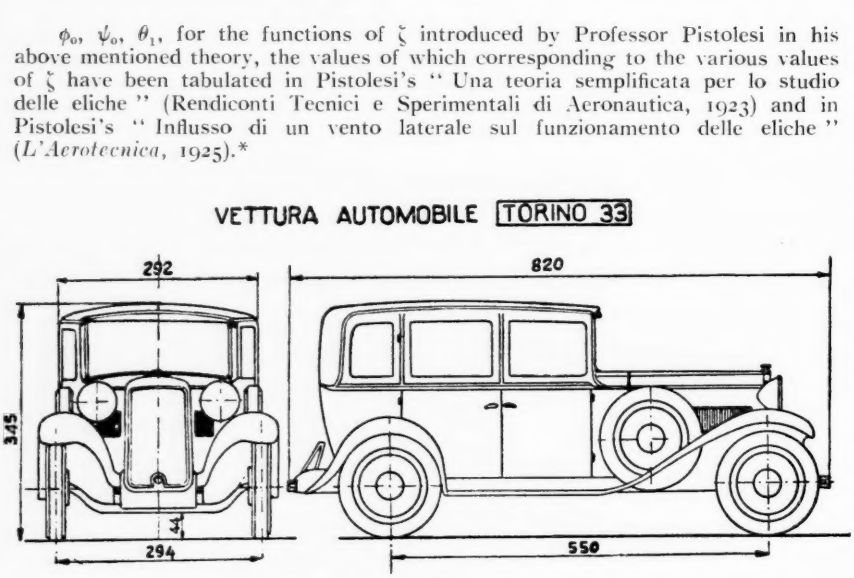


Fig. 68.

(δ) for the tangent of the effective angle of incidence α_e corresponding to the apparent incidence α, which for the range of α under consideration will be assumed as coincident with the angle α_e, whilst we will assume $\cos \alpha_e = 1$, whence

$$\alpha_e = \alpha - x/2\,(V+v)$$

x being the velocity increase normal to V induced by the airscrew at infinity.

Moreover the values of the velocity increases x and v corresponding to fixed values of γ and α, can be determined without difficulty by the theorems of the variation of the component of the quantity of motion of the mass of air influenced by the airscrew in the direction of V and in that normal thereto. We have respectively:—†

$$\left.\begin{aligned} \pi R^2 \rho\,[(V+v)\cos\alpha - \tfrac{1}{2}x\sin\alpha]\,2v &= T\cos\alpha - H\sin\alpha = \\ &= \rho R^4 \Omega^2\,(\tau\cos\alpha - h\sin\alpha) \\ \pi R^2 \rho\,[(V+v)(1+\cos\alpha) - \tfrac{1}{2}x\sin\alpha]\,x &= \rho R^4 \Omega^2\,(\tau\sin\alpha + h\cos\alpha) \end{aligned}\right\} \qquad (1)$$

From the first term of (1), if we neglect

$$(x/2V)\sin\alpha$$

in comparison with

$$(1 + v/V)\cos\alpha,$$

which is justifiable owing to the order of magnitude of α as of $x/2V$, we get:—

$$v/V = \sqrt{\{(\tau - h\tan\alpha)/2\pi\gamma^2 + \tfrac{1}{4}\}} - \tfrac{1}{2} = \sqrt{\{\tau_0/2\pi\gamma^2 + \tfrac{1}{4}\}} - \tfrac{1}{2} \qquad (2)$$

writing $\tau_0 = \tau - h\tan\alpha$. It is important to note that τ_0 is also with all approximation the thrust coefficient of the airscrew in an *axial wind* corresponding to the same advance/diameter ratio γ. In fact, the correction factor for τ for an incidence α of the airscrew disc is

$$t_D\,(S/R^2) = (S/R^2)\,\tfrac{1}{2}\gamma^2{}_0 c' \sum \phi_0\,(\delta)^2$$

which coincides with the expression $h\tan\alpha$ neglecting terms such as that

* See also PANETTI, "Corso di Costruzioni Aeronautiche."

† E. PISTOLESI, "Contributo allo studio dell'elica in un vento laterale" (L'Aerotecnica, 1928).
C. FERRARI, "Sul problema dell'elica con vento laterale" (L'Aerotecnica, 1928).

containing the coefficient of form drag the order of magnitude of which is so small as to make it straightaway negligible.

Thus it can be accepted *that it is permissible to calculate the velocity increase as if the airscrew were not in a side wind provided the velocity increase is taken as directed not along the airscrew but along the asymptotic wind.* This important property is confirmed by the test results, as is shown in Table III.

From the second term of (1) we have thus:—

$$x/V = (\tau \sin \alpha + h \cos \alpha) / \{ \pi\gamma^2 (1 + \cos \alpha) (1 + v/V) \} \quad . \quad . \quad (3)$$

whence

$$\alpha_e = \alpha - x/2V = \alpha - \{ \tau\alpha + (S/R^2) f(\gamma) \alpha_e \} / \{ 4\pi\gamma^2 (1 + v/V) \} \quad . \quad (4)$$

in which γ is the apparent advance/diameter ratio corresponding to the effective advance/diameter ratio γ_0, and

$$ef(\gamma) = \tfrac{1}{2}\gamma_0 [\gamma_0 c'_\infty \zeta\phi_0 + c_0 (\psi_0 + \theta_1)].$$

From (4) we get:—

$$\alpha_e = \{ [1 - \tau / \{ 4\pi\gamma^2 (1 + v/V) \}] / [1 + (S/R^2) f(\gamma) / \{ 4\pi\gamma^2 (1 + v/V) \}] \} \alpha$$
$$= \{ f_1(\gamma)/f_2(\gamma) \} \alpha;$$

and hence

$$h = (S/R^2) f(\gamma) \{ f_1(\gamma)/f_2(\gamma) \} \alpha;$$

$$(\partial h/\partial\alpha)_{\substack{\gamma=\text{const.} \\ \alpha=\text{const.}}} = (S/R^2) f(\gamma) \{ f_1(\gamma)/f_2(\gamma) \}.$$

Using the above formulæ the values of $\partial h/\partial\alpha$ were calculated making $S/R^2 = 0.19$; $\zeta = 0.035$, and assuming $c'_\infty = 2.8$; $c_0 = 0.01$; getting the results: $\phi_0 = 1.467$; $\theta_1 = 0.425$; $\psi_0 = 0.62$.

The whole of the calculation is summarised in the following table:—

γ	τ	γ_0	$f(\gamma)$	$f_1(\gamma)$	$f_2(\gamma)$	$\partial h/\partial\alpha$ calculated	$\partial h/\partial\alpha$ experimental
0.3	0.0055	0.303	0.0635	0.99	1.0180	0.0118	0.0114
0.25	0.0167	0.263	0.048	0.96	1.022	0.0086	0.0083
0.2	0.025	0.226	0.0365	0.91	1.02	0.0062	0.0064
0.15	0.0288	0.178	0.023	0.835	1.025	0.0035	0.0042

The agreement between the calculated and experimental results shown in the last column of the table, is very good even for the lowest advance-diameter ratios. The importance of this result, and of that stated above, made clear by Figs. 54, 55, regarding the influence of α on the coefficients τ and κ, consists essentially in the possibility which the results brings *of determining the aerodynamic data of an airscrew necessary for the calculation of the interference set up by the airscrew on the other parts of the aeroplane, from the characteristics of the airscrew calculated or derived experimentally for the axial wind condition.*

The influence of the rotation of the airscrew on the lift of the horizontal tail surface is clearly shown by the curves in Figs. 56, 57, 58, 59. It can be seen at once that the added lift increases as the advance/diameter ratio of the airscrew decreases. The relative added lift, however, decreases at the higher incidences, as is explained at once, at least qualitatively, remembering that an increasingly smaller portion of the horizontal tail surface is swept by the airscrew slipstream as the angle of incidence increases.

Advantage is gained with regard to good interpretation of the results and formulation of conclusions by comparing the results of the tests with those obtainable using the theory based on the theory of the perfect fluid which, therefore, does not take into account the damping of the vortices and the consequent deformation of the airscrew slipstream.

If in determining the lift of the tail surfaces we neglect the rotational velocity increases induced by the airscrew, which produce essentially a dissymmetry in the distribution of the circulation along the span of the horizontal tail surface,

and consider this surface as completely immersed in the slipstream, the lift coefficient c_p becomes:—

$$c_p = c'_{po}\,(1 + 2v/V)^2\,(\alpha - \alpha_{ie})$$

in which c'_{po} is the angular coefficient of lift of the horizontal surface with airscrew stationary, the velocity increase v being thus zero, whilst α_{ie} is used to denote the change in incidence at the horizontal tail surface produced by the airscrew.

But

$$\alpha_{ie} = x/\{V\,(1 + 2v/V)\}$$

in which x is the added velocity already defined normal to V.

We have

$$c_p = c_{po}\,(1 + 2v/V)^2 - c'_{po}\,(x/V)\,(1 + 2v/V) \quad . \quad . \quad . \quad (5)$$

The first term of the second member of (5), in which c_{po} is the lift coefficient of the horizontal tail surface with airscrew stationary, defines the influence of the velocity increase produced by the airscrew, whilst the second term corresponds to the deflection effect of the stream. Formula (5) is thus formally identical with the formula developed by General Crocco* to synthetise the interference of the airscrew on the horizontal tail surface.

The values of the velocity increases $2v/V$ and x/V corresponding to the various incidences used for the tests were calculated for the values of $\gamma = 0.30$, 0.25, 0.20, 0.15, 0.10, using formulæ (2) (3) and the curves of Figs. 52, 53, the calculation as a whole being summarised in Table III in which are also given the calculated values of c_p side by side with the values determined experimentally for the horizontal tail surface rectangular in plan with control angle of 0° and 15°. The curves of the calculated c_p are also included in Figs. 56, 59.

TABLE III.

						Control angle 0°		Control angle 15°	
$\alpha°$	γ	τ	h	$1+v/V$	x/V	c_p theoret.	c_p experim.	c_p theoret.	c_p experim.
0°	0.1	0.0305	0	1.357	—	—	—	0.616	0.55
	0.15	0.0288	0	1.174	—	—	—	0.38	0.375
	0.20	0.025	0	1.089	—	—	—	0.291	0.30
	0.25	0.0167	0	1.049	—	—	—	0.245	0.27
	0.30	0.0055	0	1.008	—	—	—	0.216	0.245
5°	0.1	0.0305	0.0002	1.357	0.0335	0.3322	—	0.911	0.755
	0.15	0.0288	0.00038	1.174	0.0174	0.2238	0.195	0.5787	0.58
	0.20	0.025	0.0007	1,112	0.01039	0.1801	0.18	0.545	0.482
	0.25	0.0167	0.0010	1.04	0.0628	0.158	0.17	0.3855	0.425
	0.30	0.0055	0.00137	1.009	0.00322	0.14568	0.159	0.349	0.39
10°	0.10	0.0308	0.00045	1.357	0.0682	0.636	—	1.186	0.84
	0.15	0.0293	0.0009	1.175	0.0362	0.4215	0.35	0.7675	0.67
	0.20	0.0256	0.0015	1.09	0.0213	0.337	0.33	0.6168	0.59
	0.25	0.0177	0.0021	1.042	0.0127	0.2929	0.31	0.5168	0.55
	0.30	0.0067	0.0029	1.01	0.00708	0.267	0.295	0.4695	0.575
15°	0.10	0.031	0.0008	1.358	0.1048	0.946	—	1.38	0.785
	0.15	0.0296	0.0014	1.194	0.0545	0.618	0.385	0.902	0.632
	0.20	0.0265	0.00225	1.10	0.0333	0.464	0.36	0.676	0.565
	0.25	0.0192	0.0033	1.044	0.0203	0.38	0.345	0.555	0.532
	0.30	0.0088	0.0045	1.013	0.01185	0.34	0.34	0.495	0.505
20°	0.10	0.0315	0.0118	1.36	0.1435	0.765	—	1.436	0.67
	0.15	0.0306	0.00202	1.18	0.0768	0.5043	—	0.8715	0.52
	0.20	0.027	0.00327	1.092	0.0464	0.3933	—	0.6452	0.47
	0.25	0.021	0.0047	1.046	0.0293	0.3415	—	0.5416	0.455
	0.30	0.0115	0.0065	1.016	0.01815	0.312	—	0.4803	0.45

* Crocco, "Elementi di Aviazione," pp. 573 et seq.

These curves show that the agreement between theory and experiment is on an average fairly good, provided the high angles of incidence above 10 degrees are not included. Generally speaking, the agreement is best for the advance/diameter ratios farthest away from the values corresponding to the lower experimental pitch of the airscrew. Whilst there is no obvious explanation of this latter fact, the cause of the notable discrepancies between the theoretical and experimental results at the higher angles of incidence is immediately obvious from Fig. 62 in which the configurations of the slipstream are shown for angles of the incidence of 15° and 20°, taking an assumed constant mean deflection of the stream.

It is seen that even for $\alpha = 15°$ about 40 per cent. of the horizontal tail surface is out of the slipstream. Under such circumstances the theoretical determination of the aerodynamic characteristics of the horizontal tail surfaces is beset with great difficulties, especially owing to the phenomena of diffusion and dissipation of the vorticity due to viscosity. It is logical, however, to expect a very considerable decrease of the added velocity at the location of the horizontal tail surface, and hence also of its lift. This is confirmed, moreover, by the fact that the angle for maximum lift decreases as the advance/diameter ratio decreases (Figs. 56, 59).

For a better comparison between the experimental results and those yielded by the simplified theory developed above, it is usful to re-write (5) in another form. From the graph reproduced as Fig. 60, with the incidences α as abscissæ and the angles of deflection x/V as ordinates for various values of γ, it is at once obvious that, in complete agreement with expectations from the theory of the airscrew in a side wind, within the range of the incidences α considered

$$x/V = \phi(\gamma)\,\alpha \qquad . \quad . \quad . \quad . \quad . \quad (6)$$

or, in other words: *The angle of deflection of the stream is proportional to the incidence for every advance/diameter ratio of the airscrew.* The values of $\phi(\gamma)$ for every value of γ are shown in the same graph (Fig. 60) and in Table IV.

Now, introducing equation (6) into equation (5) and denoting β the angle of the curve of no lift of the horizontal tail surface against the airscrew axis, we get:—

$$c_p = c'_{po}\,(1 + 2v/V)^2\,[\alpha\,(1 - \phi(\gamma)/\{1 + 2v/V\}) + \beta]$$

whence it can be deduced that the angular coefficient of lift of the horizontal tail surface in the presence of the airscrew is constant for every value of γ and equal to:—

$$c'_p = c'_{po}\,(1 + 2v/V)^2\,(1 - \phi(\gamma)/\{1 + 2v/V\}) = c'_{po}\,(1 + 2v/V)^2\,[1 - \phi_1(\gamma)] \qquad (7)$$

whilst the variation of the angle of no lift of the profile becomes

$$\Delta\varepsilon = \beta\,\{\phi(\gamma)/(1 + 2v/V)\}/\{1 - \phi(\gamma)/(1 + 2v/V)\} = \beta\,\phi_1(\gamma)/(1 - \phi_1(\gamma)) \qquad (8)$$

since obviously

$$\phi_1(\gamma) = \phi(\gamma)/(1 + 2v/V).$$

The values of c'_p and $\Delta\varepsilon$ calculated using the formulæ given above are tabulated in Table IV and shown graphically in Fig. 61, side by side for purposes of comparison, with the values obtained experimentally.

TABLE IV.

γ	Control 0° c'_p experim.	Control 15° c'_p experim.	Control 0° $\Delta\varepsilon^\circ$ experim.	$1 + 2v/V$	$\phi(\gamma)$	$\phi_1(\gamma)$	$1 - \phi_1(\gamma)$	$\Delta\varepsilon^\circ$ calc.	c'_p calc.
	1.62	1.62	—	—	—	—	—	—	—
0.3	1.81	1.85	0°.25	1.02	0.04	0.0392	0.9608	0°.3	1.62
0.25	1.95	1.97	0°.50	1.084	0.075	0.069	0.931	0°.5	1.79
0.2	2.1	2.09	0°.80	1.18	0.126	0.107	0.893	0°.88	2.02
0.15	2.24	2.35	1°.6	1.348	0.206	0.153	0.847	1°.40	2.45
0.10	—	3.2	2°.9	1.714	0.39	0.228	0.772	2°.2	3.66

It is seen that the agreement is notably better as regards the deflection $\Delta\varepsilon$ of the angle of no lift, and hence as regards the deflection of the stream due to the airscrew, than it is for the angular coefficient c'_p, and owing to this circumstance the approximation of the theoretical results is satisfactory only for $\gamma \leq 0.25$.

The curves of Figs. 63, 64, 65, 66, give the coefficient of rolling moment c_{mr} defined by equation (9)

$$c_{mr} = M_r / \rho S V^2 l_m$$

in which l_m is the mean chord of the horizontal surface (l_m = area/span), as a function of the incidence α for the various values of γ considered above. The rolling moments, as known, are the result of the rotational velocity increases induced by the airscrew, which at two sections of the wing, equi-distant from the plane of symmetry, set up incidence differences $\Delta\alpha$ that may be assumed to be equal and opposite, so that for an element at a distance r from the plane of symmetry, if ω be the induced rotational velocity increase, $\Delta\alpha = \pm r\omega/(V + 2v)$. Hence, the rolling moment acting on the whole horizontal surface becomes :—

$$M_r = 2\rho V \int_0^R c'_p l r^2 \omega \, (1 + 2v/V) \, dr = \rho \, (V^2 D S/\gamma) \, h c'_p \, (\omega/\Omega) \, (1 + 2v/V) \quad . \qquad (10)$$

in which $\bar{h}$ is a constant the value of which depends on the distribution law of the velocity increases induced by the airscrew along the span of the tail plane and on the plan form of the horizontal tail surface, whilst D denotes the diameter of the airscrew. Substituting for M_r the value given by (10), we get :—

$$\begin{aligned} c_{mr} &= (D/l_m) \, (c'_p/\gamma) \, \bar{h} \, (\omega/\Omega) \, (1 + 2v/V) \\ &= (D/l_m) \, (c'_{po}/\gamma) \, [1 - \phi_1 \, (\gamma)] \, \bar{h} \, (\omega/\Omega) \, (1 + 2v/V) \end{aligned} \qquad (11)$$

The mean velocity increases ω/Ω can be calculated using

$$\omega/\Omega = (2\kappa/\pi)/\{\gamma \cos \alpha \, (1 + v/V)\} \quad . \quad . \quad . \qquad (12)$$

Using (11) for the determination of the coefficients c_{mr} for incidence $\alpha = 0°$, taking for the values of the c_{mr} those given by the tests (curves Figs. 63, 66), we get for $\bar{h}$ the values shown in the table below.

γ	0.3	0.25	0.20	0.15
1,000 κ	2.4	4.95	6.2	6.7
1,000 (ω/Ω)	5.1	12.2	18.4	24.2
c_{mr}—rectangular surface ...	0.025	0.034	0.055	0.105
c_{mr}—elliptical surface ...	0.024	0.032	0.052	0.103
c_{mr}—triangular surface ...	0.02	0.03	0.046	0.083
$\bar{h}$ { rectangular surface ...	0.278	0.127	0.105	0.105
$\bar{h}$ { elliptical surface ...	0.278	0.127	0.105	0.105
$\bar{h}$ { triangular surface ...	0.243	0.122	0.096	0.091

It is at once apparent that the variation of the constant $\bar{h}$ with variation either of γ or of the plan form is fairly small with the exception of the neighbourhood of $\gamma = 0.3$, which is near the experimental pitch of the airscrew. It is also noteworthy that for the horizontal tail surface rectangular in plan, if in actual fact the lift were constant along the span and the velocity increases induced by the airscrew were also constant, the value of $\bar{h}$ would be equal to $1/6 = 0.167$.

With increasing α, according to (11), the coefficients of rolling moment would remain constant, neglecting the small variations of ω/Ω with equal γ, due to the operation of the airscrew in a side wind, for all the angles of incidence to which the rectilinear portion of the lift curve corresponds. In actual fact the experimental curves although showing horizontal tangents for $\alpha = 0$ decrease rapidly even for an angle of incidence some way below the critical angle. This is a consequence of the fact, already pointed out, that with increasing incidence an increasingly large portion of the tail plane is removed out of the slipstream, the

portion thus removed being that farthest away from the axis and hence being the most effective in setting up rolling moments. In fact the moment, which throughout never reaches anything but very small values, undergoes a reversal for a value of α which for $\gamma = 0.30$ is rather less than 10°, whilst the peak of the lift curve occurs barely at 16°. This also explains the very high value of $\overline{k}$ for advance/diameter ratios near γ_s corresponding to the experimental pitch. In fact in the neighbourhood of $\omega = 0$, the ratio of the maximum increase to the mean increase rises rapidly because over a part of the radius the increase itself changes sign for a value of the advance/diameter ratio near, but smaller than γ_s.

To take account of the fact that the horizontal tail surface is not completely immersed in the slipstream, it would be necessary to multiply the coefficient c_{mr} given by (11) by the reduction factor

$$\Delta = [1 - (L^2 a^2 / R^2)\,[1 + \phi_1\,(\gamma)]^2]^{3/2}$$

in which L denotes the distance between the horizontal surface and the airscrew disc. This shows that the decrease of the coefficient of rolling moment with incidence is given, at any rate qualitatively, by the theoretical formula.

It is also of interest to express the rolling couple set up on the tail plane by the rotational velocity increases induced by the airscrew, as a function of the engine torque C applied to the airscrew.

We have:—

$$\mu = M_r\, C = (c_{mr} S l_m / \kappa R^3)\,\gamma^2.$$

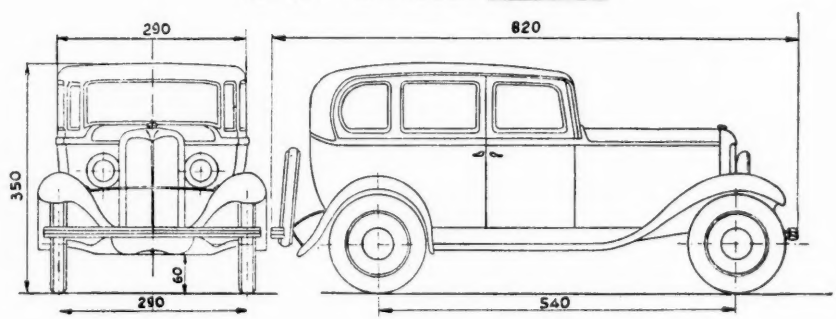


Fig. 69.

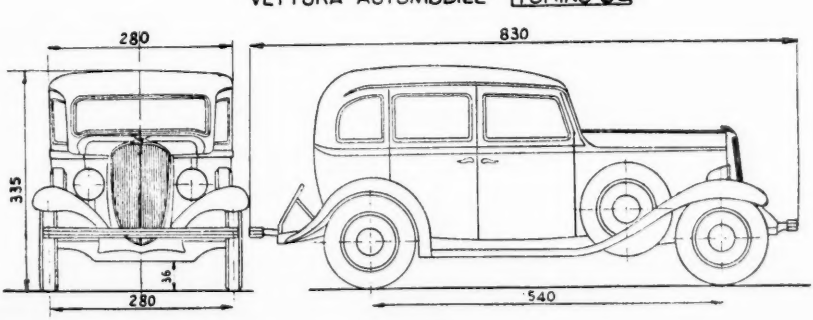


Fig. 70.

The values of μ as a function of a for the various values of γ were calculated for the rectangular tail surface and are shown graphically in Fig. 66.

The further tests of the series planned by the Laboratorio Aeronautico of Turin have as their object, as already said, the determination of the influence of the airscrew on the lift of the horizontal tail surface when a wing is present, with various positions of the wing with respect to the airscrew and various positions and distances of the horizontal tail surface. The results of these tests, executed using the installation described in the first series of the " Rendiconti Sperimentali " and the six-forces balance described in the present report, will be given in a forthcoming series of the " Rendiconti."

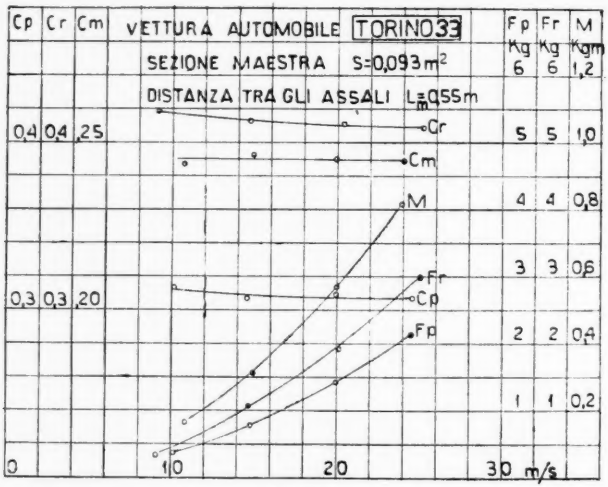


Fig. 71.

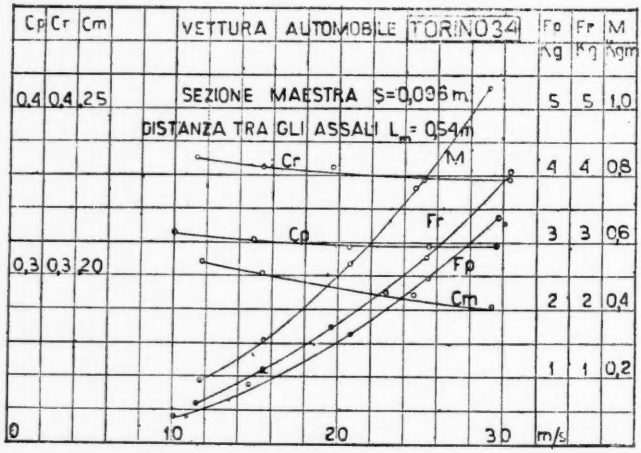


Fig. 72.

" Torino 33, 34, 35 " (Figs. 68, 69, 70, 71, 72, 73, 74)

These are three models of motor cars. The " Torino 33 " has a vertical windscreen and spare wheels on the sides of the engine. The " Torino 34 " has a slightly sloping windscreen and the spare wheel at the back of the car in the luggage carrier; it has very large wings which project considerably beyond the wheels. The " Torino 35 " has a considerably more sloping windscreen and the wings set in closer to the body, which at the rear is slightly cambered. Like the

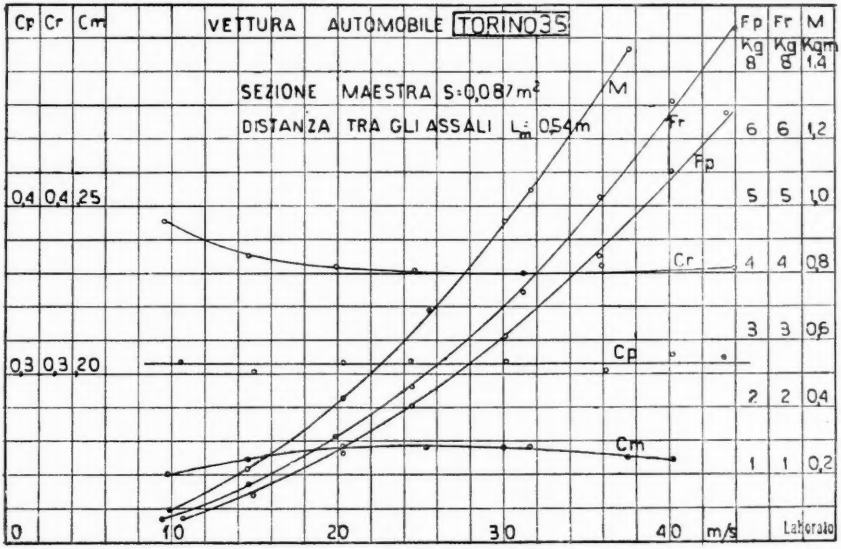


Fig. 73.

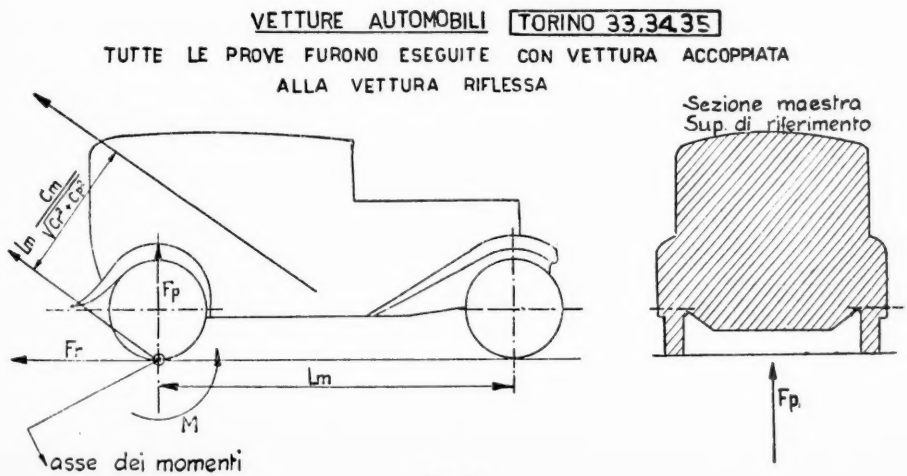


Fig. 74.

" Torino 33 " it has the spare wheels on either side of the engine, and has both front and rear buffers.

The tests of each car were carried out with duplicate models (reflection method) to take account of the ground reaction. They were extended to include not only the drag at various speeds comprised between 10 and 40 metres per second (33 and 131 feet per sec.), but also the lift and aerodynamic moment about a straight line normal to the plane of symmetry and joining the points of contact of the rear wheels on the ground. To this end one of the models was fixed rigidly to the walls of the wind tunnel whilst the reflected model was suspended by wires on the balance so as to obtain a measurement of the action exercised by the wind on one of the cars only. For the drag tests both the cars were connected to the balance so that the forces measured were twice the value of the drag proper to each car. The results of the tests are shown graphically in Figs. 71, 72, 73. An appreciable decrease of the drag coefficient c_r (referred to the maximum cross-section of the car, derived as apparent contour of the car in a vertical plane normal to the plane of symmetry) is recorded as between the " Torino 33 " and the other two models, but hardly any difference between the " Torino 34 " and " Torino 35," the exact values of c_r for the three cars being 0.41, 0.358 (12.6 per cent. reduction), 0.36 (12.3 per cent. reduction) respectively for a tunnel wind speed of 30 metres per second (98 feet per sec.). But as the maximum cross-sections of the cars differ fairly considerably, the forces acting on the models for the same wind speed are not in the same proportion to each other as the c_r values given above. Thus for a speed of 30 metres per second (98 feet per second) the reactions in kg. on the models are as follows: " Torino 33 " 4.3 kg. (9½lb.), " Torino 34 " 3.88 kg. (8½lb.) (reduction of 9.8 per cent.), " Torino 35 " 3.5 kg. (7lb. 12oz.) (reduction of 18.5 per cent.), to which correspond, for speed of 30 metres per second and for models to scale 1 : 5, required h.p. values of 43, 38.8 and 35 h.p. respectively.

There is very little difference between the three models as regards the lift. All three are lifting, the c_p values being respectively 0.308, 0.318, 0.306, to which for full-scale cars would correspond load reductions of 81 kg. (178lb.), 86.5 kg. (190lb.) and 74.5 kg. (164lb.) respectively, and inclinations of the resultant aerodynamic force relative to the horizontal of 30° 50′, 41° 50′, 40° 40′. From the curve of the moments referred to the distance l_m between axes of the wheels it is deduced that the line of action of the aerodynamic resultant intersects the ground at a horizontal distance x/l_m from the axis of the moments which for the three cars under consideration is given by :—

$$x/l_m = \{ c_m / \sqrt{(c_p^2 + c_r^2)} \} \{ c_p / \sqrt{(c_p^2 + c_r^2)} \} = c_m c_p / (c_p^2 + c_r^2)$$
$$= 0.245 \times 0.308/(0.308^2 + 0.41^2) = 0.285$$
$$= 0.19 \times 0.318/(0.318^2 \times 0.358^2) = 0.284$$
$$= 0.178 \times 0.306/(0.36^2 + 0.306^2) = 0.244.$$

In other words, the aerodynamic resultant for the three models tested is displaced considerably to the rear.

REVIEWS

An Introduction to the Theory of Elasticity

By R. V. S. Southwell, M.A., F.R.S., F.R.Ae.S. Published by the Clarendon Press. Price 30/-.

This is the most important book on stress matters which has appeared for many years. Professor Southwell is well known for his many papers on structures, especially in connection with the design of rigid dirigibles, but in this book he has dealt with such matters more generally, and in a form which is of the utmost importance to those engaged in stress calculations for aircraft.

The book deals with most if not all of the problems to be met with in aeronautical design, and also with such matters as the whirling of shafts and elastic stability generally, and discusses these problems directly from the elastic stability and strain energy standpoint, which methods in Professor Southwell's hands prove to be extremely powerful. The point of view adopted is often novel, and my general impression is that the methods described in this book will, in course of time, cause many of the methods used to-day to become obsolete. In many cases he criticises effectively existing formulæ, such as a commonly used shear formula on page 226, and shows that it may err on the unsafe side. Strain energy due to shear is also discussed, probably the first time this matter has been referred to in a text-book; this subject is of importance in connection with the design of steel spars for aircraft.

A book of this type was badly wanted. In the course of ordinary stress calculations, using known formulæ, it is very easy to forget that many of these are based on elastic theory and to overlook the importance of using this theory in cases where the ordinary formulæ do not apply.

This is a really notable book and no one engaged in aeronautical design can afford to be without it.

A Treatise on Screws and Worm Gear, their Mills and Hobs

By P. Cormac. Published by Chapman and Hall. Price 21/-.

This is a treatise dealing solely with screws, their various applications and methods of manufacture. The treatment is necessarily largely mathematical, and it is of some interest to compare the treatment with that used in aeronautical textbooks in connection with propellers.

But possibly the most interesting parts of the work are those dealing with methods of cutting the various forms of screw gears, forms of hobs, etc., with mathematical analyses of the required shapes which should be of considerable interest to those engaged in the design of such gears.

Worm gears transmitting large powers are not used in aeronautical work, but there is much in this book which is instructive in connection with the design of such gears for retractable chassis and similar applications and the chapters on methods of generation should be most useful.

Diesel Aircraft Engines

Published by Paul H. Wilkinson, Brooklyn, U.S.A.

This book contains a description of all aircraft Diesel engines manufactured; it also includes a chapter on the history of these engines and several chapters on constructional details, future development, etc.

It is at least possible that the Diesel type of internal combustion engine is the engine of the future for long range commercial aviation, and possibly also for certain types of military aircraft. The only country which has used such engines extensively is Germany, and the information available suggests that they are as reliable as the normal motor using petrol.

So far, the principal advantage which has accrued to aviation from the Diesel motor seems to have been that its existence has spurred the makers of petrol engines to improve the efficiency of their engines, but this latter development has necessitated the use of high octane fuel which is likely to be even more costly than normal petrol.

Even in its present state the Diesel offers the advantages of a much cheaper fuel, an almost complete absence of fire risk, a lighter power plant for ranges exceeding eight hours; and also certain minor advantages such as the absence of electrical interference with wireless signals. The fuel used should have special advantages in tropical countries where it is known that the evaporative loss when using petrol may be very high.

A book of this type, which contains a statement of the case for the Diesel engine and a description of the principal types, is to be welcomed as it assists one to keep in touch with the development of this important type of engine which may possibly be the successor of the petrol engine in all forms of mechanical transport. If the editor of this book is correct, Junkers Diesel motors, made by Napier and Son, under licence, are to be fitted to one of the new flying boats now being made by Short Bros. for Imperial Airways. This, if true, is a most interesting development and may have far-reaching consequences.

The 602nd Lecture read before the Society since its foundation on January 12th, 1866.

PROCEEDINGS

A meeting of the Society was held on Monday, January 20th, 1936, in the Lecture Theatre of the Institution of Electrical Engineers, at Savoy Place, Victoria Embankment, London, W.C.2, when Professor W. L. Bragg, O.B.E., M.A., Sc.D., F.R.S., lectured on "The Theory of Alloy Structures."

In the chair: Mr. D. R. Pye, Deputy Director of Research, Air Ministry.

The CHAIRMAN: He expressed the regrets of the President (Lieut.-Colonel J. T. C. Moore-Brabazon), who was unable to attend owing to indisposition.

The Society must count itself very fortunate in the fact that Professor Bragg had consented to lecture to its members. The lecturer was Langworthy Professor of Physics at Victoria University of Manchester, a Fellow of the Royal Society, and was awarded the Nobel Prize for Physics in 1915, after having taken his degree and having served as Lecturer at Trinity College, Cambridge.

During the great war Professor Bragg had carried out most valuable work on sound ranging, as Technical Adviser to the Map Section at General Headquarters in France.

THE THEORY OF ALLOY STRUCTURES

BY

Professor W. L. BRAGG, O.B.E., M.A., Sc.D., F.R.S.

1. I wish in the first place to express my warmest thanks to the Council of the Royal Aeronautical Society for the honour they have done me in inviting me to read this paper on alloy structures. I have no claim whatever to be considered a metallurgist or an expert in any way on the technical uses to which alloys are put. I only venture to give this lecture because nowadays a physicist has a finger in most pies. The discoveries of physics concern all sciences interested in the structure and properties of matter. Since ultimately the properties of matter are dependent upon its atomic structure, and this is the field in which physics has made such rapid recent advances, its findings have become of especial importance. In particular, the determination of atomic arrangement in solid bodies has made it possible to formulate new generalisations in many sciences, and to view old problems from a new angle. To take one example, the atomic structures of the majority of important mineral types have been found out during the last decade. The classifications of the mineralogist, based on crystal habit often in defiance of their chemical compositions, have been shown to be fully justified by a beautifully simple scheme of geometrical arrangement, which shows why certain minerals exist and others equally plausible from a chemical viewpoint do not, and accounts for crystalline forms and properties. Again, the study of atomic arrangements shows that the laws of valency in inorganic chemistry have a much more far-reaching and illuminating interpretation than had been suspected. There is evidence that the marvellous ability of the organic chemist to decipher the constitution of complex molecules may be even further extended by the physicist's determination of the precise configuration of these

molecules, and a beginning has been made on the configuration of molecules entering into the structure of living organisms.

2. These advances have been made by observing the diffraction of X-rays by the array of molecules in solid bodies. The more perfectly regular the molecular array, the easier is it to deduce the arrangement from the diffraction effects. Hence the X-ray method of investigation has come to be associated with crystals, in which the highest perfection of arrangement is attained. It cannot be over-emphasised, however, that the use of crystals is only a means towards an end, the easiest method of approaching a problem which has a much wider significance than that of the crystalline state. It is curious to contemplate this leap into prominence of the study of the crystalline state, due to the advent of X-ray analysis. Crystals used to be regarded as the pretty scientific playthings of a select body of enthusiasts, who had very little contact with other scientists and lived in a geometrical world of regular figures such as those which excited the imaginations of the Greek mathematicians of classical times. The only application of their study was to mineralogy, because the earth's crust provides the conditions of freedom from interference and slow growth through the ages which produce the most perfect crystalline forms. It is no exaggeration to say that X-ray analysis of crystals now has an influence upon more diverse sciences, and an application to more technical problems, than almost any branch of physics.

3. Metals and alloys are crystalline and offer ideal material for X-ray analysis. The polished surface of an alloy sample reveals a mosaic of crystals separated by irregular boundaries. In a range of composition where a single phase is formed, these crystals are all alike in nature, but have different orientations. When the alloy splits up into more than one phase, these crystals differ in kind as well as in orientation.

Three major problems of alloy structure may be outlined. In the first place there is the investigation of the ideal atomic arrangement inside each crystalline block, regarded as a perfect sample of that particular type of crystal. How are the atoms placed, and how does the arrangement alter as we pass from one phase to the next in an alloy system? Here X-ray analysis is a powerful weapon with which a successful attack can be made on almost any structure. Our knowledge is limited rather because there is such a vast number of possible alloys and there has as yet been only time to examine a few systems, than because of any insuperable difficulty of analysis.

In the second place there is the more theoretical problem of analysing the interplay of forces which causes the metal atoms in alloys to take up the configurations we observe, and of explaining such characteristics as conductivity, specific heat, thermal expansion, magnetic constants, and so forth, which the structures display. As in other atomic problems, classical mechanics is almost powerless in this field and an appeal to the new mechanics must be made. The problem is very complex, but considerable advance has already been made and there are many signs that a satisfactory fundamental theory of alloy structure is on the way.

Finally, there is the problem of what may be termed the " geography " of the alloy structure. It is composed of crystals which differ in shape, which may be distorted and strained, which may have been pulled into preferred orientations, and so forth. The mechanical properties of a block of alloy depend in a sensitive way on such characteristics as these. In this field theory has a long way to go before it can catch up with the vast body of practical knowledge which has been patiently collected. We need to develop new lines of attack in this most difficult field where theory lags so conspicuously behind practice, for from a technical point of view these characteristics are the most important of all. I feel incompetent to deal with the last aspect and have an excellent excuse for

leaving it severely alone because I understand you have invited Mr. Gough to survey it in a subsequent lecture, when its treatment will be in much more capable hands than mine. I will confine myself to the first two aspects, investigating the structure of the individual crystals which compose the alloy and explaining these structures theoretically.

4. The method of analysing crystal structure by X-rays may be outlined by describing what we would see if we had an " X-ray eye," an eye which received an impression when X-rays entered it and which distinguished between the different wave-lengths of X-rays as our colour sense actually enables us to appreciate the contrasts between impressions due to visible light of various wave-lengths. When white light falls on opal or a piece of mother-of-pearl we see a play of colours. These colours are produced by a laminar structure. In the formation of the opal the amorphous silica is apparently deposited in or subsequently develops numerous nearly equi-distant layers each of which reflects a small proportion of the incident light. A single layer would reflect the white light as such, but when the effects of a series of layers are superimposed light of one colour is reflected far more strongly than that of all others. This colour corresponds to a wave-length for which the waves from successive planes are just " in phase," adding their effects because the reflected waves are in step. For other colours there is a misfit and the waves from successive planes are destroyed by interference. The same effect in a less striking form is seen in mother-of-pearl, because the mollusc lays down the smooth inner surface of the transluscent shell in a series of thin layers. If we were to look at the surface of an alloy illuminated by X-rays with our supposed " X-ray eye " it would show a play of colour like that of the opal. As the block was turned about, each crystallite would give flashes of pure colour all over its surface, the colour changing for each orientation. Interference effects are produced with X-rays like those of the opal with visible light because the crystalline structure has numerous sheets of atoms which reflect the X-rays at equally spaced successive planes. We are robbed of the æsthetic pleasure of seeing these effects because we cannot " see " X-rays, but we can enjoy it at second-hand by substituting the photographic plate or ionisation chamber for the eye. By measuring the angle at which X-rays of a given wave-length are diffracted, and the settings of the crystal at which the effect occurs, it is possible to derive the spacings of the atomic sheets and the geometrical arrangement of the atoms which produces these spacings.

The most suitable technique for examining alloys is that of the " powder photograph." The alloy is ground to a fine powder, such as would pass through a mesh of 200 to the inch. A speck of this powder (about as much as would make a pin head) is placed on a hair at the centre of a cylindrical camera which has a photographic film around its inner surface. A beam of monochromatic X-rays normal to the axis of the cylinder falls on the mass of powder. The tiny crystals in the powder diffract the X-rays and the diffracted beams are registered by the film. Each alloy structure produces its own characteristic pattern of lines on the photographic film. The alloy can be identified by its pattern in the same way that a chemical element can be identified by the lines of its spectrum. The powder photograph is therefore a powerful means of recognising alloy phases, which can be applied to minute quantities of material.

The further step of deducing the atomic arrangement from the powder photograph is in general a difficult one to make. In the case of complex crystals the pattern is so crowded with lines that it is not easy to analyse their significance. Fortunately most alloy structures are either very simple or are slight variants from a relatively simple type, and there is no insuperable difficulty in reading the meaning of their powder photographs. Many phase diagrams of binary alloys have now been checked by X-ray analysis. The pioneer work in this field was begun over a decade ago by Westgren. The familiar phase diagram

for an alloy between metals A and B is one in which temperature is plotted vertically, and the composition of the alloy between pure A and pure B is plotted horizontally. Lines on it outline regions of temperature and composition within which there is a single solid phase, two solid phases in equilibrium, solid plus liquid, or liquid. As one passes at normal temperatures from pure A to pure B, one traverses alternately regions of single phase and of two phases. X-ray analysis has shown that each of the characteristic phases which appear as composition varies, and which are usually denoted by the letters α, β, γ, etc., is a structure of distinctive crystalline type. For instance, if we start with pure silver and alloy it with cadmium, the α structure formed with small percentages of cadmium is like that of silver itself. Pure silver has atoms on the corners and face centres of a cubic array, and cadmium atoms merely replace a certain proportion of the silver atoms. As the percentage of cadmium is increased, a new β phase appears and co-exists with α. It has silver atoms at the corners and cadmium atoms on the centres of cubes. Further increase produces pure β and then a mixture of β and γ. The γ phase is a very complex cubic structure containing 52 atoms in the unit of structure. The next ϵ phase is hexagonal close packed, and the final η phase another hexagonal structure similar to that of pure cadmium.

It is difficult to exaggerate the wealth of detailed knowledge which can be got by subjecting an alloy system to X-ray analysis. We can find the crystalline structure of each phase, its boundaries, its density and coefficient of thermal expansion, and the way in which the metal atoms dispose themselves amongst the positions offered to them by the crystalline array of the phase structures. This last point has turned out to be of unsuspected importance. Rearrangements of the atoms inside the solid crystal take place under thermal treatment, with consequent important changes in physical properties. Formerly knowledge about the phase diagram had to be got by observing such effects as thermal arrests on cooling, and by quenching the alloy from different temperatures, polishing and etching a face, and examining it under the microscope. Some alloy systems have been very fully investigated in this way, and X-ray analysis has merely confirmed the phase diagrams and discovered the crystalline structures. In other cases, however, it has been shown that the accepted phase diagrams are far too simple. There is a wealth of phases or modifications of phases which is not revealed by the metallurgical technique. We may take as an instance the Al-Cr system, to which the phase diagram in the International Critical Tables vaguely assigns three phases whereas a recent X-ray analysis by A. J. Bradley shows that there are about fifteen phases at room temperatures. An enormous programme of work extends before us. Each binary system will repay an intensive X-ray study which must be an expert research of a year or two in duration, and when these researches are exhausted we have the ternary and more complex systems to turn to.

The complexity would be overwhelming but for the fact that X-ray analysis has shown the major types of structure in alloys to be few in number. The changes are rung on a few simple types and slight modifications of them. This is a most encouraging feature, for it shows many relationships in the alloy systems of different pairs of metals, and gives us reason to hope that we will find rules by which phase diagrams can be predicted.

5. A foreshadowing of these rules is already seen in the work of the theoretical physicists who have handled the problem of alloy structure by the new mechanics. The point on which we must focus our attention is that of the electronic energy—levels in the metal. A metal is an electro-positive element. One or more electrons, according to its characteristic valency, can be removed from the neutral atoms by the expenditure of a relatively small amount of energy, leaving it a positive ion. When the isolated atoms come together to form the solid metal, the energy levels of these valency electrons are profoundly modified

(the measure of an energy level is that of the work required to take an electron from that level and remove it to the outside of the metal, in other words, it is a measure of the firmness with which an electron in that particular state is bound to the metal). The sharply defined energy levels of the isolated atoms become extended bands in the metal. This is, of course, formally true for all electronic levels in any solid body. It is the peculiar nature of the modification of the valency electron levels in a metal which gives rise to the characteristic metallic properties. The electrical conductivity, for instance, is to be ascribed to the fact that a band of possible electronic states is only partially filled by the available electrons.

A beautiful application of the new mechanics to the problems of alloy structure has been made by H. Jones, who has gone a long way towards the explanation of the empirical rule formulated by Hume-Rothery. Hume-Rothery's rule states that alloy phases of corresponding structure appear in different binary systems when the ratio of valency electrons to atoms is approximately the same. Jones has correlated this rule with the accommodation of the electrons in energy levels in the alloy structure. He has shown that the configuration of the sheets of atoms in each typical structure is one which depresses the electronic energy levels in an important way. The direct forces between an atom and its neighbours, to express it somewhat loosely, are of minor importance in typical alloys. The atoms take up positions which relegate their common stock of electrons to low levels, a result which depends on the geometrical arrangement as a whole rather than on the relation of one atom to its nearest neighbours. This new viewpoint of the nature of a metal or alloy is of fundamental importance.

It cannot be too strongly emphasised that if we pry into the causes for the inner structure of metals we must throw overboard our notions of mechanical reactions of the classical type, and whole-heartedly adopt the conceptions of the new mechanics. Classical mechanics not only is of no service, it is definitely misleading. An attempt is still sometimes made to put new wine in old bottles, to think of such problems as slip and distortion as if they were engineering problems on a little atomic scale. Such attempts are foredoomed to failure.

I have confined myself in this written account to generalities, and have not tried to illustrate points of detail by diagrams and photographs such as were shown in the lecture when delivered. It would take too much space to go into detail in a satisfactory way, and reference may be made to a recent address to the Institute of Metals (Jour. Inst. Metals, LVI, p. 275, 1935) where some points are elaborated. I have contented myself with trying to outline the way in which a body of fundamental theory about alloy structure is being developed, largely based on the detailed analysis of atomic arrangement by X-rays.

I was specifically invited by your Secretary to say whether the new theories would throw any light on the ultimate limits to the mechanical strength of alloys. It would be foolhardy for me to attempt to answer the question. Each man can only be an expert in his own line, and can only form valid judgments when he knows a large number of relevant facts. In the present case, we can arrange our experts in a series, starting with the theoretical physicist at one end, and continuing with the experimental physicist, the metallurgist, the engineer, and the man who actually handles the engine. The knowledge of each expert overlaps somewhat with that of the man to right or left of him in the series. They can talk to each other with understanding and cast light from a new angle on each other's problems, because of their common knowledge. One cannot expect, however, that a similar collaboration will be equally fruitful between two experts further apart in the series. It would be like trying to tie together in a survey two partial triangulations which include no common fixed points. Ultimately, however, an advance in knowledge at any point will have its repercussions all along the line.

Discussion

The Chairman (Mr. D. R. Pye): He described the lecture as a most fascinating one. He confessed to a hope that the members of the Society who had heard it would dislike as much as he would the idea of having to face an examination on the subject; but he derived some comfort from the lecturer's remark that one could not hope to understand these things in an engineering frame of mind. He had passed beyond the stage at which he could hope to emerge very far from that engineering frame of mind. However, the functions of a lecture were not primarily to enable those who heard it to acquire knowledge, but to stimulate their interest in matters about which they knew little or nothing; and from that point of view—speaking for himself, at any rate—the lecture had been one of the most delightful to which he had ever listened under the ægis of the Society.

Quite early in the lecture, Professor Bragg had said that one might ask how a physicist could dare to talk about the structures of alloys. But the lecture had certainly answered that question. The subject was typical of those with regard to which engineers needed the physicist to lighten their darkness. Speaking as an ignorant user of alloys, the Chairman said he had always felt that their development had been to a large extent a matter of chance, that the work of the metallurgists had been rather in the nature of groping and occasionally catching a prize. The familiar duralumin contained about 4 per cent. of copper, about ½ per cent. of magnesium and about ½ per cent. of manganese. By what process had those percentages been decided? Probably an enormous amount of ground had been covered by laborious trial and error methods, and it had been found that that particular mixture made an extremely effective and strong material, a material of very high specific strength for its weight. But he was always impressed by the number of other combinations that *might* have been tried, and by a feeling that there might be big prizes waiting round the corner. It was just the kind of really fundamental knowledge of which Professor Bragg had been attempting to give some idea in his lecture, which would lead to the winning of those prizes. Inasmuch as Professor Bragg had mentioned Dr. Hume-Rothery, it was of interest to mention that the Aeronautical Research Committee, knowing of Dr. Hume-Rothery's work at Oxford, had lately made a special grant to assist him in his researches, more especially in exploring the hopeful types of alloys of magnesium. One hoped that the ideas and mental pictures that had been put forward in the lecture by Professor Bragg would gradually find their way into the minds of engineers, and that when we were all thinking, not perhaps in terms of wave mechanics, but at any rate in terms of atomic and crystal structures, the groping to which he believed even the metallurgists would confess that the discovery of alloys in the past had been due, would give place to the much more positive and direct building up of the kind of materials that we needed.

Mr. J. L. Hodgson (*Associate Fellow*): He felt that the audience had been most interested in the new window which Professor Bragg had opened, giving a view into a world which was at present little known to engineers. He asked if there was available any book giving a general summary of these new methods, outlooks and discoveries that could be easily understood by the engineer. The new ideas, he suggested, might not be difficult to understand when once they had come into common use. Three hundred years ago, when such men as Galileo and Torricelli were investigating the cause and nature of a vacuum, one of the theories as to why a pump was able to suck water was that the " threads of the air " became stretched and pulled the liquid up! Men had of necessity to think things out in terms of their existing knowledge. At that date they knew nothing of the weight of the great ocean of air that pushed the liquid into the space evacuated by a pump plunger.

Then again, although the mass of a body was easily thought of in a rough way in terms of the muscular effort required to set it in motion or to stop it when in motion, experience showed that heavy bodies flung from the same catapult travelled further and faster than lighter ones. The lighter bodies must therefore have the greater mass, since they required a greater force to hurl them at the same speed! It was not until the forces resisting motion were analysed out and accounted for that the concept of Mass as proportional to Force divided by Acceleration emerged and became clear.

These things, which were now commonplace, presented extraordinary difficulties three hundred years ago when men were endeavouring to found the sciences of hydraulics and mechanics.

Similarly, although the concepts and methods of wave mechanics are a closed book to most of us to-day, they might eventually become as easy to understand as the engineer's idea of mass, and the present explanation of why a pump sucks water.

A matter which had interested him in the course of Professor Bragg's lecture was the variable way in which atoms responded to different rates of cooling. He would like an explanation of this apparent viscosity effect in the atom.

Discussing electrical and magnetic effects, Mr. Hodgson referred to the fact that at very low temperatures—4° or 5° absolute—certain metals were perfect conductors. It was thought that when the metals were in that perfectly conducting state the electrons were running round quite freely, without any resistance; otherwise the metals would not be perfect conductors. He asked whether X-ray photographs would indicate the kind of arrangement of the electrons. Professor Bragg had not differentiated between atoms and electrons, and Mr. Hodgson did not quite see how the X-ray photographs indicated what the electrons were doing—whether there were reflections from the electrons as well as from the atoms.

Recently the General Electric Company of America had put forward a new magnetic alloy, made of aluminium, nickel, copper and iron which would lift 60 times its own weight. It was said that this alloy would in many cases replace electro-magnets. He asked whether X-ray analysis could tell us anything about its construction.

Referring to structure of materials, Mr. Hodgson pointed out that the gem diamond, which was a single perfect crystal, was weak in structure and easily fractured along the cleavage planes, whereas the Brazilian carbonado diamond, in which the crystals were small and interlocked, was immensely strong. The ordinary gem diamond would break to pieces if hammered, but the usual result of such treatment in the case of the Brazilian carbonado diamond was to dent both the hammer and the anvil! Apparently this immense extra strength was due to the arrangement of the crystals, and not to any particular arrangement of the atoms. He asked if Professor Bragg could give information on the point.

Three hundred years ago men had begun to frame theories to explain the properties of gases. These theories were in practice now fairly complete and consistent, thanks to the invention of such devices as the suction pump and the steam engine. The present age, with its immense accumulation of empirical data, was interested in framing theories to explain the properties of solids. Professor Bragg's lecture showed the enormous amount of new and important detail that such reasoned and systematic study was able to bring out.

Professor BRAGG: He agreed warmly with Mr. Hodgson's view that the new wave mechanics would become progressively easier to understand. This had in fact happened to some extent already. The first formulation of the new ideas was so abstruse that very few scientists appreciated their significance, but they were now presented in a much simpler form. It was a question of language, and of becoming accustomed to a new viewpoint. Perhaps he had exaggerated

the difficulty of the new mechanics because of his personal experience, but he felt sure he had not exaggerated the necessity for a complete re-orientation of one's views. Mr. Hodgson had referred to Torricelli's experiment and the difficulty scientists had at that time in conceiving such a thing as atmospheric pressure. He might recall that one fervent supporter of the idea that invisible threads were holding up the mercury, proved his point to his own satisfaction by saying that if he closed the upper end of the tube with his finger he could feel the threads pulling it!

As regards the response of the atoms in an alloy to different types of heat treatment, a body of theory well supported by experiment had been built up. The author and Dr. Williams in this country, Borelius in Sweden, and Dehlinger in Germany, had been responsible for its development. The " Order-Disorder " change in alloys was especially interesting because it lent itself to a fairly simple mathematical treatment which proved to explain the phenomena well. At high temperatures the atoms of the alloy were arranged in a disordered way owing to the violent thermal agitation; at low temperatures they segregated with an ordered scheme. The interesting point found experimentally and explained theoretically was the existence of a critical temperature, above which disorder reigned, and below which order set in extremely rapidly. Order won at the lower temperature because it was the state of lower potential energy. As an alloy was cooled, however, the rate at which the atoms could exchange places rapidly decreased since they could only exchange if a thermal blow were received sufficient to get them past each other. The alloy, if rapidly cooled, might " freeze " into a condition which was really unstable, but changed extremely slowly at low temperatures. The effects of quenching and annealing on the order-disorder change were a fascinating study.

Mr. Hodgson asked what information X-rays could give about the electrons responsible for the metallic conductivity. Directly, they gave none. X-rays were scattered by the electrons in the substance, and so X-ray analysis found the position of electrons, but these were the electrons firmly bound to the nucleus. It could be shown theoretically that the effect of the loosely bound conductivity electrons on the X-rays was vanishingly small. On the other hand, X-ray analysis indirectly gave exceedingly valuable evidence. It determined the atomic arrangement, and provided a starting point for the theoretical physicist. The latter could deduce the nature of the field of force in the metal, and so the properties conferred upon it by the electrons in the upper energy levels. Magnificent work had been done by H. Jones in this country, particularly in indicating the explanation of Hume-Rothery's rule.

The question of magnetism was of especial interest because this property, unlike the majority of the mechanical properties, depended mainly on internal structure. There was every hope that a successful theoretical treatment would soon be forthcoming. Work done on the Heusler alloys had already been most suggestive.

The difference in behaviour of the ordinary single crystal diamond and the composite carbonate was another instance of " structure-sensitive " properties, or properties which depend on the nature of the crystal aggregate as well as on that of the individual crystals. Metals afforded endless such instances, it was in fact the most important of all technical problems and so far the one towards whose solution the least advance had been made.

Replying to a question whether contact was being maintained with work carried out in Russia, Professor Bragg said that the exchange of scientific ideas was as fully carried out as with other countries.

Mr. W. O. Manning (*Fellow*): What light would the method of crystal analysis shed on the phenomenon of Young's modulus? Young's modulus was certainly a mechanical property of metals which was extremely important from a structural point of view; yet, if one considered the modulus of pure iron,

and then added to the iron a little carbon or nickel or chromium, one found that the modulus would remain practically the same. However, the alloy was heat treated, one could not alter the modulus. If it were possible to devise a method by which the modulus could be raised in value, the resulting material would be considerably improved from the point of view of its use for certain parts of aircraft structures. Mr. Manning assumed, from the lecture, that the amount of energy used in stretching the material within the limits of proportionality was taken up by increasing the energy of the electrons. It would seem, therefore, that by heat treating the metal in different ways and adding small quantities of alloys, the energy which the electrons were capable of taking up as the result of a small amount of stretching remained nearly the same. Of course, the ultimate strength and other mechanical properties might differ very widely. He asked if Professor Bragg would confirm a statement made in a treatise some time ago dealing with a rather similar matter, that a theoretical value could be written down for the strength of most of our materials, which value was generally something like three times that which was actually obtained. It would be valuable to have a definite explanation for that if possible, because if one knew the cause of the difference one might be able to remove it and hence to use very much better materials than are being used at present.

Professor BRAGG: Mr. Manning had raised a subject which in the lecture he had tried to avoid! The discrepancy between the theoretical strength of materials and the observed strength was often far greater than Mr. Manning had indicated. He could not remember the exact figures for such a material as rock salt, where one could work out theoretically what the strength should be, but he indicated the order of the discrepancy by saying that whereas theoretically the strength should be 10,000 it was actually 50. There was a colossal discrepancy, and it appeared that all materials break not by giving way suddenly all over, but by a tearing which commenced at a crack; it was always a tear and never a sharp break. Because it was so difficult to write down the mathematical equation for a tear, it was still extremely difficult to treat theoretically such features as ultimate strength. The definiteness of the Young's modulus was extremely interesting, and he believed the theoretical men would be getting on to it very soon. Because it was a " structure-insensitive " characteristic and rather independent of chance effects such as those arising from small quantities of alloying material, it was a property for which a theoretical treatment has a direct significance.

Mr. H. SUTTON (Royal Aircraft Establishment, *Fellow*): He was particularly interested in the iron-nickel-aluminium magnet, which he believed was first introduced by a Japanese worker, Mishima. There one had the case of an addition of aluminium to an alloy composed of iron and 25 per cent. of nickel, and which was ordinarily a non-magnetic material, and to the layman it would seem that it was the last thing in the world to start with for producing the world's best magnet. It was interesting to know that such remarkable changes could be effected by the addition of a little aluminium to a non-magnetic material; one looked forward very much to further development on the lines mentioned by Professor Bragg in his lecture and the continuation of his work, aided by his splendid team of workers in Manchester and other parts of the country. As a metallurgist who must confess to be one of those who had been groping in the darkness for many years, Mr. Sutton said that he rejoiced to be living at a time when a few lighthouses were shining on this very large ocean of blackness. Formerly, when seeking for a new alloy, one required a very large assortment of pure metals, a large amount of inspiration and plenty of time if one hoped to achieve anything at all. It was very gratifying indeed to find that Professor Bragg, Dr. Hume-Rothery, and others, who looked at the matter through atomic spectacles, had been able to smile on particular combinations of elements which were providing useful series of materials. Mr. Sutton mentioned par-

ticularly additions to magnesium and said that already, by adding zinc and aluminium, investigators were forming a very valuable series of alloys. That being so, he said there was every reason for optimism; if the metallurgists continued to pursue their work on those lines in collaboration with physicists working on atomic structures, they might achieve useful results very much more quickly than results had been achieved in the dark ages of the past.

Discussing the problem that in some materials rupture was easily produced and tended to extend rapidly, Mr. Sutton said that very often, after working a piece of magnesium-rich alloy, one found that in one direction it had properties which were desirable, whereas in another direction, owing to the orientation of the majority of the crystals, the properties were undesirable. Very often, however, these materials were required to possess useful mechanical properties in all directions; so that still more information was required from the inner-structure experts.

With regard to the problem of brittleness in materials, one hoped for some help from our scientific friends on the question of the rupture of metals. Very often metals subjected to alternating stresses failed by rupture through the crystal, whereas under the prolonged application of steady stress the more prevalent form of failure followed the crystal boundaries. So that it was necessary to learn a good deal more about crystals, and it was to research work of the kind that Professor Bragg and his assistants were doing that metallurgists and engineers would have to look for guidance in dealing with such problems.

Professor BRAGG: The series in which he and his colleagues had been particularly interested—they felt that that series might be of some use to the aircraft industry eventually—were the alloys of iron, cobalt and nickel with each other and with aluminium. When tackling such systems one found there were so many ramifications that any one of those systems provided years and years of work in order to find out all that might happen in the structures. It was only the lack of hands that was holding up the work; men must have a certain amount of training before they could do it. Further, the X-ray investigator was not generally a trained metallurgist, and was uncertain as to whether he had prepared his alloys in the right way. Thus, it was by co-operation with the metallurgist that real progress would be made.

The CHAIRMAN: He drew attention to a new alloy he had seen at the Exhibition of the Physical Society recently, which alloy had a density of about 16.5 (which compared with a density of 11 in the case of lead). He was not sure of the constitution of the alloy, but he was told that there was a certain amount of tungsten in it. He asked whether it was possible to make a binary or ternary alloy of greater density than any of its constituents, and if so, whether it was possible, conversely, to make an alloy of a lower density than any of its constituents. The latter possibility would be of great interest in aviation, even if the specific strength were not necessarily high. There were certain uses for which a material having half the weight of magnesium would be very valuable, even if it had only a very modest strength.

Professor BRAGG: He was not very well qualified to answer the question, but his impression was that all such alloys as had been mentioned were fairly regular in their properties; the density varied with composition as if the volume occupied by each kind of metal remained approximately constant throughout the range, which implied that one could not look for very startling peculiarities of density. There were some curious cases; for instance, nickel-iron alloys did some queer things, but even there the variations were on rather a small scale.

Captain J. LAURENCE PRITCHARD (Secretary of the Society): Dealing with the ultimate application of the work described by Professor Bragg, he asked whether one was likely ever to be able to predict the properties of an alloy from knowledge of the atomic structure of its constituents. If that could be done, it meant that in the future, when one saw a picture of an atomic structure

which one had not seen before, one could say that a particular metal or alloy having that particular form of structure would always have certain properties. Could one work from the structure itself and say that although the properties of the material had not been tested, it would probably have certain properties, just as in the ordinary atomic table there was a certain number of elements, the properties of which had been predicted in advance, and in the past one or two had been discovered having properties exactly as predicted?

Professor BRAGG: He was sure we should never be able to do all that Captain Pritchard had mentioned, for that was an ideal; but he was also sure that those concerned with the study of the structure of metals would be able to help a long way towards it. He drew a parallel between future progress in this connection and the progress which had been made with regard to dyes. In the past, people had dyed their clothes with indigo and woad, etc., which they had obtained from plants. In the early days of chemistry someone might have asked whether it would ever be possible to predict that such and such a compound would make a good dye. At first the chemists could not answer that question in the affirmative; but the chemists had continued to provide knowledge, and as knowledge accumulated those who were closely concerned with the technical side began to be influenced by this knowledge and able to use it. That was why he felt that, although it was very difficult to say what direct contributions work such as that described in the paper would make (though the case of magnetic alloys was one in which the investigators were very near to being of real help), one should continue to find out all one could about various systems that were likely to be interesting, such as the iron, cobalt, nickel, aluminium, chromium systems. Eventually men having a different kink to their minds, with a greater technical knowledge and greater knowledge of what was required, would find that the new understanding of alloys thus gained indicated promising directions in which to work to secure the properties desired. That was the way in which things actually worked out in practice; one could not do the whole thing in one step.

On the motion of the CHAIRMAN, a hearty vote of thanks was accorded Professor Bragg for his lecture and for his very interesting replies to questions raised.

THE STRESSING OF RIGID-JOINTED FRAMES

BY

Capt. J. MORRIS, B.A.

(*Awarded the R.38 Memorial Prize, January,* 1936.)

INTRODUCTION

The investigation of the strength of a rigid-jointed frame is a problem of considerable practical importance. The precise effects of the secondary stresses arising from the rigidity of the joints have in the last half century been the subject of much speculation. But the calculation of these secondary stresses is extremely tedious by any existing method and in consequence they have rarely been ascertained with any degree of accuracy. The first real attack on the problem was made by Manderla in his Munich Polytechnic prize essay—" The Calculation of Secondary Stresses which Occur in Simple Trusses "—published in 1880 in *Allgemeine Bautzeitung.* Manderla made his solution tractable by virtue of his reasonable assumption that the linear displacements of the panel points of a rigid-jointed braced frame will be approximately the same as if the joints were pin-jointed and that the primary loads in the members of the frame had their pin-jointed values. But, instead of allowing the frame to be linearly deflected on this basis, Manderla complicated his analysis by artificially maintaining the panel points in their original positions and then imposing on members of the frame deformations to take account as far as possible of the effects of the true displacements.

Manderla's solution, although comprehensive, is very laborious to apply, more particularly if account is taken of end load deflection effects, which effects are extremely important in aeronautical structures. Moreover, Manderla confined his essay to the plane frame.

Manderla's pioneer work has been followed up by a train of solutions more or less on the same lines. Grimm, in his book " Secondary Stresses in Bridge Trusses," gives a very useful account of the historical development of the subject. He mentions three principal variants of Manderla's method, viz., Müller-Breslau's, Ritter's and Mohr's all of which *inter alia* neglect, for simplicity, end load deflection effects.

The early theories on secondary stresses were formulated mainly by German professors, who also furnished the main literature on the subject. But no marked advance on Manderla either in novelty of outlook or simplicity of treatment was made prior to the promulgation in America in 1930 of a successive approximation process by Professor Hardy Cross. A description of this process was given in his paper, entitled " Analysis of Continuous Frames by Distributing Fixed End Moments," and published in the Proceedings of the American Society of Civil Engineers.

The Hardy Cross method marks a definite epoch in the history of the subject. It introduced a new idea in iteration in which the iteration is carried out not with current values of the variables but with the differences of consecutive current values. In its generalised form for the plane frame, as given by the present writer in his paper " The Calculation of the Loads and Bending Moments

in the Members of a Plane Braced Frame," prepared for the Aeronautical Research Committee, it may be summarised as follows:—

The deformed frame is regarded as having all the joints (supposed rigid) pinned to fixed points in space, and the end fixing moments required to hold the various members in their displaced positions, but without any rotation of the joints are ascertained. If now we release the fixing moments at one of the joints so that it becomes free to rotate about the point to which it is pinned and at the same time keep all the other joints fixed in their current positions then the released fixing moments will be balanced out amongst the members meeting at that joint, in accordance with a definite scheme of distribution. At the same time appropriate moments will be carried over to the other ends of the members concerned. The distributed and carried-over moments will be algebraically additive to the original fixing moments at the ends of the members. In this way all the other joints may be released in turn, it being a condition that during the release of any particular joint all the other joints are held in the positions they then occupy. The process is continued until practically nothing remains to be distributed or carried over. Finally, all moments at the ends of each member are algebraically summed. These sums will then give the actual bending moments at the ends of members of the frame for the positions in which the joints are pinned in space.

If, therefore, we can find the true values of the linear displacements of the joints or close approximations to them, then the foregoing process will clearly lead to correspondingly accurate values for the end moments of the frame under the given external loads.

A feature of the Hardy Cross process is the fact that it deals all the time with actual bending moments. The drawback is the large number of variables involved simultaneously. For instance, a simple rectangular braced frame with one side encastered requires the consideration of eight bending moments as variables, whereas physically only two angular rotations of the joints are involved and these alone are the essential variables. In the case of other than relatively simple frames the Hardy Cross method tends to become laborious mainly owing to the large number of variables iterated.

The writer, when engaged upon the application of the Hardy Cross method to braced aeronautical structures, noticed that the underlying principle was in essence an iteration process for indirectly solving the simultaneous equations which normally arise for the angular rotations of the joints. The question then presented itself as to whether it was possible to solve the appropriate equations directly by a simple iteration process. This the writer succeeded in doing, and thereby the analytical basis of all iteration processes of the Hardy Cross type was established.

The writer believes that in the present paper he has produced a practical working solution for braced frames taking into account all reasonable and essential factors. In particular he believes that he has for the first time given a useful treatment of the rigid-jointed space frame. The features to which he would like to call attention are:—

> The formulation of a simple method for expressing the equations of equilibrium (including end load deflection effects) with economy of variables.
>
> The solution of the equations by a novel system of iteration which appears to have considerable practical advantages over existing methods.

From the experience already gained in the analysis of actual structures it appears that the rigidity of the joints may give rise to an appreciable accession of strength in a structure as compared with the strength of the same structure with the joints treated as pin-jointed.

1. Deformation of a Single Member of a Plane Frame

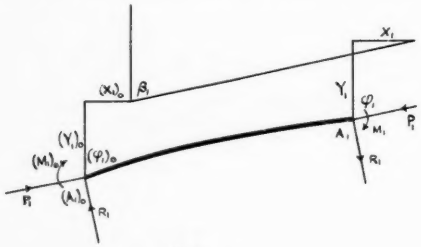


Fig. 1.

Referring to Fig. 1, let $(A_1)_0\,A_1$ be a member of a plane frame in which loads are applied at the joints only. These loads may be forces or couples, but are supposed to act in the plane of the frame. Let $(X_1)_0$, $(Y_1)_0$, $(\phi_1)_0$, X_1, Y_1, ϕ_1, be the displacements (supposed small) of the points $(A_1)_0$, A_1, from their unstrained positions, the X's and Y's being translatory displacements and the ϕ's angular displacements. P_1 is end load in the direction parallel to the unstrained line of the member and R_1 is reaction normal to the line and in the plane of the frame. $(M_1)_0$, M_1, are the end bending moments. The directions of the ϕ's and M's are taken positive when clockwise, the M's being regarded as the actions of the appropriate joints on the members.

If the member is originally at an angle β_1 to the vertical (measured positive as in the figure) then the relative displacements of A_1 with regard to $(A_1)_0$ in the directions normal to and parallel to the unstrained line of the member are

$$\delta_1 = [Y_1 - (Y_1)_0] \sin\beta_1 - [X_1 - (X_1)_0] \cos\beta_1$$
$$\epsilon_1 = [Y_1 - (Y_1)_0] \cos\beta_1 + [X_1 - (X_1)_0] \sin\beta_1.$$

The following equations may readily be proved

$$\epsilon_1 = P_1 x_{11}$$
$$M_1 = -(z_{11}/\Delta_1)\,\delta_1 + (y_{11}/\Delta_1)\,\phi_1 + \{(l_1 z_{11} - y_{11})/\Delta_1\}\,(\phi_1)_0$$
$$(M_1)_0 = -(z_{11}/\Delta_1)\,\delta_1 + (y_{11}/\Delta_1)_0\,(\phi_1)_0 + \{(l_1 z_{11} - y_{11})/\Delta_1\}_0\,\phi_1$$

where x_{11} = compression (or extension) of the member in the direction of its length due to unit compressive (or tensile) load in that direction.

y_{11} = deflection of the point A_1 normal to the length of $(A_1)_0\,A_1$ due to unit load at the point A_1 in that direction when the point $(A_1)_0$ is held fixed.

z_{11} = slope at the point A_1 due to the same unit load; also deflection of the point A_1 due to unit couple at that point.

ϕ_{11} = slope at the point A_1 due to the unit couple.

For a uniform member in compression it may be shown that

$$M_1 = -\frac{6E_1I_1}{l_1^2}\,\frac{1}{\phi(a_1/2)}\,\delta_1 + \frac{4E_1I_1}{l_1}\,\frac{\phi(a_1)}{\psi(a_1)}\,\phi_1 + \frac{2E_1I_1}{l_1}\,\frac{f(a_1)}{\psi(a_1)}\,(\phi_1)_0$$

$$(M_1)_0 = -\frac{6E_1I_1}{l_1^2}\,\frac{1}{\phi(a_1/2)}\,\delta_1 + \frac{2E_1I_1}{l_1}\,\frac{f(a_1)}{\psi(a_1)}\,\phi_1 + \frac{4E_1I_1}{l_1}\,\frac{\phi(a_1)}{\psi(a_1)}\,(\phi_1)_0$$

where $a_1 = (l_1/2)\sqrt{(P_1/E_1I_1)}$,

l_1 = length of member,

I_1 = flexural moment of inertia,

E_1 = Young's modulus of elasticity,

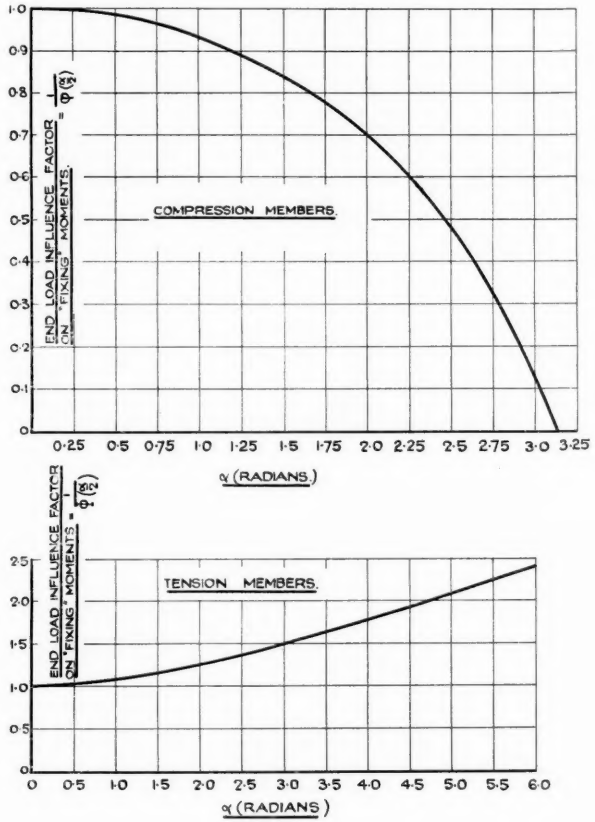
and $f(a)$, $\phi(a)$, $\psi(a)$, are the Berry functions

$$f(a) = 6\,(2a\ \mathrm{cosec}\ 2a - 1)/(2a)^2$$
$$\phi(a) = 3\,(1 - 2a\cot 2a)/(2a)^2$$
$$\psi(a) = 3\,(\tan a - a)/a^3.$$

For a member in tension the corresponding functions are

$$F(\alpha)=6(1-2\alpha \operatorname{cosech} 2\alpha)/(2\alpha)^2$$
$$\Phi(\alpha)=3(2\alpha \coth 2\alpha-1)/(2\alpha)^2$$
$$\Psi(\alpha)=3(\alpha-\tanh \alpha)/\alpha^3.$$

Curves for the appropriate functions of α in the moment equations both for compression and tension are given in plates I, II and III.


END LOAD INFLUENCE FACTOR ON "FIXING" MOMENTS = 1/φ(α)
COMPRESSION MEMBERS.
α (RADIANS.)
END LOAD INFLUENCE FACTOR ON "FIXING" MOMENTS = 1/φ(α)
TENSION MEMBERS.
α (RADIANS)

EFFECT OF END LOAD ON 'FIXING' MOMENTS.

PLATE I.

The following equation for the equilibrium of the member also applies

$$M_1+(M_1)_0+P_1\delta_1+R_1l_1=0.$$

For the equilibrium of a joint (say joint r) we must have

$$\Sigma M_r=M_E$$

where M_E is the externally applied couple; if this is zero

$$\Sigma M_r=0.$$

$$\text{or } \Sigma\left[\frac{6E_rI_r}{l_r^2}\frac{1}{\phi(\alpha_r/2)}\delta_r\right]+\left[\Sigma\frac{4E_rI_r}{l_r}\frac{\phi(\alpha_r)}{\psi(\alpha_r)}\right]\phi_r+\Sigma\left[\frac{2E_rI_r}{l_r}\frac{f(\alpha_r)}{\psi(\alpha_r)}(\phi_r)_0\right]=0.$$

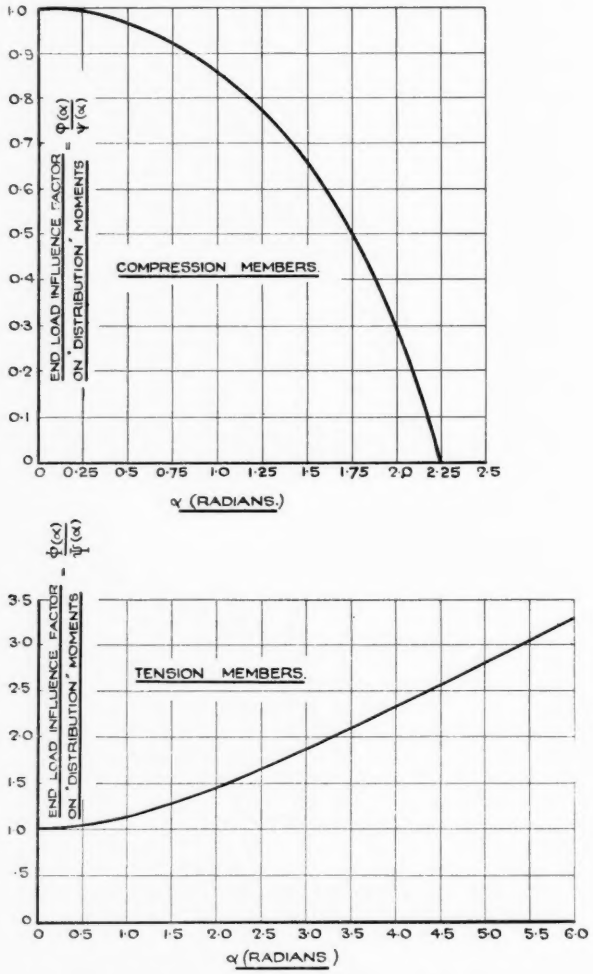
In addition

$$\Sigma (P_r \sin \beta_r - R_r \cos \beta_r) = X_E$$

and

$$\Sigma (P_r \cos \beta_r + R_r \sin \beta_r) = Y_E$$

where X_E, Y_E, are the externally applied load (if any) at the joints in the directions of X and Y respectively.



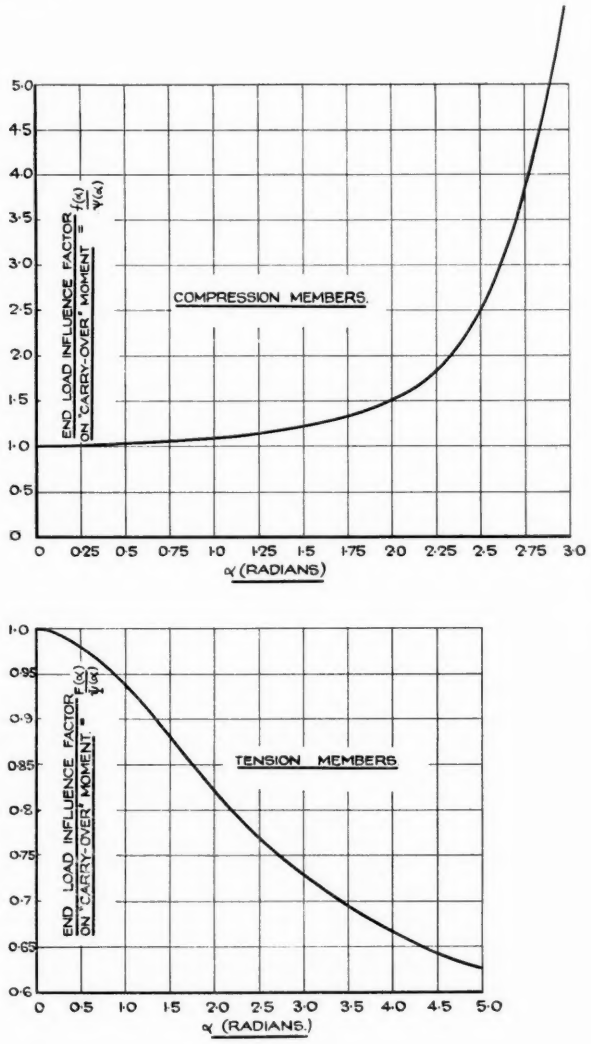
EFFECT OF END LOAD ON "DISTRIBUTION" MOMENTS.

PLATE II.

2. SIMPLE EXAMPLE OF A PORTAL TYPE FRAME

As an example of the use of the equations consider the case of a simple square portal with one side encastered, as in Fig. 2, with a load W acting vertically downwards at the point A_1.

In the first place we neglect the end load deflection effects and the changes of length of the members (all of which are supposed to be uniform and of equal elastic properties).



EFFECT OF END LOAD ON "CARRY-OVER" MOMENTS.

PLATE III.

In these circumstances let δ_{A1}, δ_{B1}, ϕ_{A1}, ϕ_{B1}, be the deflections and angular rotations at A_1 and B_1 respectively, then

$$\delta_{A1}=\delta_{B1}=\delta \text{ say.}$$

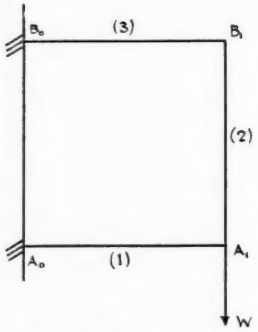


FIG. 2.

For the equilibrium of the joints at A_1, B_1, we have

$$-(6EI/l^2)\,\delta+(8EI/l)\,\phi_{A1}+(2EI/l)\,\phi_{B1}=0$$
$$-(6EI/l^2)\,\delta+(2EI/l)\,\phi_{A1}+(8EI/l)\,\phi_{B1}=0$$
$$\therefore\ \phi_{B1}=\phi_{A1}=0.6\,\delta/l.$$

Also from the fact that the sum of the shears in members (1) and (3) vertically upwards at A_1 and B_1 must be W we find that

$$(24EI/l^3)\,\delta-(12EI/l^2)\,\phi_A=W$$

so that

$$\delta=5Wl^3/84EI.$$

Thus the bending moment at A_1 on member (1) is

$$M_1=-(6EI/l^2)\,\delta+(4EI/l)\,\phi_{A1}=-3Wl/14.$$

Similarly the bending moment at B_1 on member (3) is

$$M_3=-3Wl/14.$$

The bending moments at the encastered ends of members (1) and (3) must therefore be $-2Wl/7$ while the bending moments at the ends of member (2) must be $+3Wl/14$.

From these bending moments we may find the consequential end loads in the members.

Thus the end loads in members (1) and (3) will be

$$(2\times 3Wl)/14l=(3/7)\,W$$

being compressive in member (1) and tensile in member (3). Similarly the end load in member (2) is $W/2$ and is tensile.

With these values for the end loads we may next proceed to a better approximation in which account is taken of the extension or compression of the members and also of the end load deflection effects.

Let X_{A1}, Y_{A1}, X_{B1}, Y_{B1}, be the linear displacements of the points A_1, B_1, then

$$X_{A1}=-X_{B1}=(3/7)\,Wx_{11}$$
$$Y_{B1}-Y_{A1}=(W/2)\,x_{11}.$$

The equations may now be formed as follows:—

For the equilibrium of the joints A_1 and B_1 respectively

$$-\frac{6EI}{l^2}\frac{l}{\phi(a_1/2)}Y_{A1}-\frac{6EI}{l^2}\frac{l}{\Phi(a_2/2)}2X_{A1}+\frac{4EI}{l}\left\{\frac{\phi(a_1)}{\psi(a_1)}+\frac{\Phi(a_2)}{\Psi(a_2)}\right\}\phi_{A1}$$
$$+\frac{2EI}{l}\frac{F(a_2)}{\Psi(a_2)}\phi_{B1}=0$$

$$-\frac{6EI}{l^2}\frac{l}{\Phi(a_3/2)}Y_{B1}-\frac{6EI}{l^2}\frac{l}{\Phi(a_2/2)}2X_{A1}+\frac{4EI}{l}\left\{\frac{\Phi(a_2)}{\Psi(a_2)}+\frac{\Phi(a_3)}{\Psi(a_3)}\right\}\phi_{B1}$$
$$+\frac{2EI}{l}\frac{F(a_2)}{\Psi(a_2)}\phi_{A1}=0.$$

Also sum of the shears in members (1) and (3) vertically upwards at A_1 and B_1 must be W.

Hence

$$\frac{12EI}{l^3}\frac{l}{\phi(a_1/2)}Y_{A1}-\frac{6EI}{l^2}\frac{\phi(a_1)}{\psi(a_1)}\phi_{A1}+\frac{12EI}{l^3}\frac{l}{\Phi(a_3/2)}Y_{B1}-\frac{6EI}{l^2}\frac{\Phi(a_3)}{\Psi(a_3)}\phi_{B1}=W.$$

Now X_{A1} and $Y_{B1}-Y_{A1}$ are known as are also the a's. Hence we have three equations to determine the three unknown quantities Y_{A1}, ϕ_{A1}, ϕ_{B1}. Having determined these we readily obtain the bending moments at the ends of all the members. From these we may find corrected values of the end loads and repeat the process if necessary.

3. The Braced Plane Frame with Rigid Joints

In the case of a braced structure the problem is somewhat simpler in that we may obtain first approximations to the linear displacements of the joints by assuming that these are pin-jointed and that the primary loads in the members have their ordinary pin-jointed values. After ascertaining the end bending moments on this basis we can correct up the values of the end loads to accord with the shears at the joints arising from the end moments, and thus proceed to a second approximation and so on if necessary. The problem therefore primarily resolves itself into the solution of the simultaneous equations for the angular rotations of the joints, which equations are readily obtained from the fact that the sum of the end moments at each joint is zero or some assigned value. Now in general simultaneous equations of three or more variables are troublesome to solve numerically. The solution frequently involves differences between quantities very nearly equal, so that unless the work be carried to several significant figures considerable errors are likely to arise in the results. These difficulties can be overcome to a very great extent by making use of a suitable iteration process for the solution of the simultaneous equations.

4. Solution of Simultaneous Linear Equations

Successive approximation methods based on the iteration principle have been given by Gauss and Seidel.* Recently the writer gave the outline of an iteration method which has the advantage of being carried out in a simple tabular form.† The iteration part of the method is best illustrated by an example. Suppose we wish to solve the equations

$$10x+y+2z=60 \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$x+5y+z=71 \quad . \quad . \quad . \quad . \quad . \quad (2)$$
$$5x+2y+100z=2{,}025 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Equation

(1a) $x_1=6$ obtained by putting $y=0$, $z=0$ in (1).
(2a) $y_1=13$ obtained by using in (2) value of x found in (1) and putting $z=0$.
(3a) $z_1=19.69$ obtained by using in (3) values of x_1, y_1, already found.
(1b) $x_2=0.762$ obtained by using in (1) values of y_1, z_1, already found.
(2b) $y_2=10$ app. obtained by using in (2) values of z_1, x_2, already found.
(3b) $z_2=20$ app. obtained by using in (3) values of x_2, y_2, already found.
(1c) $x_3=1$ obtained by using in (1) values of y_2, z_2, already found.
(2c) $y_3=10$ obtained by using in (2) values of z_2, x_3, already found.
(3c) $z_3=20$ obtained by using in (3) values of x_3, y_3, already found.
(1d) $x_4=1$ obtained by using in (1) values of y_3, z_3, already found.

Thus the solution of the equations (1), (2) and (3) must be $x=1$, $y=10$, $z=20$.

* See "The Calculus of Observations," Whittaker and Robinson (Blackie), pp. 255-7.
† "On a simple method for solving simultaneous linear equations by a successive approximation process," Morris (Journal of the Royal Aeronautical Society, April, 1935).

The above process would clearly prove cumbersome where a large number of variables is involved and particularly where the process is not so rapidly convergent. A great simplification can be effected by adopting an appropriate tabular method in which the iteration is carried out not with the current values of the variables, but with the differences of consecutive current values.

As an example consider the following equations:—

$$10x + 2y + 2.5z = 120.425$$
$$2x + 20y + z = 224.01$$
$$2.5x + y + 15z = 35.35$$

which are of the form

$$a_1x + b_1y + c_1z = d_1$$
$$a_2x + b_2y + c_2z = d_2$$
$$a_3x + b_3y + c_3z = d_3$$

To explain the procedure. Arrange the table in three columns, viz., one corresponding to each variable. At the head of each column write a_1x, b_2y, c_3z. In the next row express the ratios a_2/a_1, a_3/a_1; b_1/b_2, b_3/b_2; c_1/c_3, c_2/c_3; regard being had to signs, in the appropriate columns. Then in the next row put the values of d_1, d_2, d_3, with their correct signs, underlining the value of d_1. This will be the first value for a_1x. Next distribute $-d_1$ (in this particular example -120.425) in the proportions a_2/a_1, a_3/a_1, regard being had to signs, in the appropriate columns. Thus $a_2/a_1 = \frac{1}{5}$, $a_3/a_1 = \frac{1}{4}$. Hence the values to be distributed are $\frac{1}{5} \times -120.425$ $(= -24.085)$ and $\frac{1}{4} \times -120.425$ $(= -30.106)$. Next add the portion distributed to column (2) to the value d_2 above it in the same column and so obtain $+199.925$, which sum is underlined. Next distribute -199.925 in the proportions b_1/b_2, b_3/b_2 (viz., 1/10, 1/20), in the appropriate columns. We thus distribute -19.992, -9.996, as in the table. Next add, algebraically, all the quantities in column (3) and so obtain the sum -4.752 which is to be underlined. Distribute $+4.752$ as in the previous distributions. Next return to column (1) and add the quantities acquired from the preceding two distributions, but do not include the sum underlined in the column. We thus obtain the algebraic sum -19.200 which we underline. This is next distributed in the same way as the 120.425 was, *i.e.*, we distribute $+19.200$ in the proportions $\frac{1}{5}$, $\frac{1}{4}$. Continue the process in this way until the quantities to be distributed become small or negligible. Then add algebraically all the sums underlined for each column, which in the particular example gives, after five circuits

$$10x = 100$$
$$20y = 204$$
$$15z = 0.151$$

so that $x = 10$, $y = 10.2$, $z = 0.01006$.

The actual values are

$$x = 10,\ y = 10.2,\ z = 0.01.$$

Theory of the Method

Suppose we consider a system of three equations, viz.,

$$a_1x + b_1y + c_1z = d_1$$
$$a_2x + b_2y + c_2z = d_2$$
$$a_3x + b_3y + c_3z = d_3.$$

We have by the iteration process

$$a_1x_1 = d_1$$
$$a_2x_1 + b_2y_1 = d_2$$
$$a_3x_1 + b_3y_1 + c_3z_1 = d_3$$
$$a_1x_2 + b_1y_1 + c_1z_1 = d_1$$
$$a_2x_2 + b_2y_2 + c_2z_1 = d_2$$
$$a_3x_2 + b_3y_2 + c_3z_2 = d_3$$

and so on.

Clearly from the form of these equations

$$a_1(x_n - x_{n-1}) + b_1(y_{n-1} - y_{n-2}) + c_1(z_{n-1} - z_{n-2}) = 0$$
$$a_2(x_n - x_{n-1}) + b_2(y_n - y_{n-1}) + c_2(z_{n-1} - z_{n-2}) = 0$$
$$a_3(x_n - x_{n-1}) + b_3(y_n - y_{n-1}) + c_3(z_n - z_{n-1}) = 0.$$

TABLE I.

Ratios of distribution ...	(1) $a_1x = 10x$ a_2/a_1, a_3/a_1 ($\frac{1}{8}$, $\frac{3}{4}$)	(2) $b_2y = 20y$ b_1/b_2, b_3/b_2 (1/10, 1/20)	(3) $c_3z = 15z$ c_1/c_3, c_2/c_3 ($\frac{1}{6}$, 1/15)
Constants of equations ...	$d_1 = +120.425$	$d_2 = +224.01$	$d_3 = +35.35$
Distribution of -120.425	—	-24.085	-30.106
Distribution of -199.925	-19.992	$+199.925$	-9.995
Distribution of $+4.752$ ...	$+0.792$	$+0.317$	-4.752
Distribution of $+19.200$	-19.200	$+3.840$	$+4.800$
Etc.	-0.416	$+4.157$	-0.208
,, ...	-0.765	-0.306	$+4.592$
,, ...	-1.181	$+0.236$	$+0.295$
,, ...	$+0.007$	-0.070	$+0.004$
,, ...	-0.050	-0.020	$+0.299$
,, ...	-0.043	$+0.009$	$+0.011$
,, ...	$+0.001$	-0.011	$+0.001$
,, ...	-0.002	-0.001	$+0.012$
,, ...	-0.001	—	—
,, ...	—	-0.001	—
Algebraic sum of quantities distributed ...	$+100$ $\therefore x = 10$	$+204$ $\therefore y = 10.2$	$+0.151$ $\therefore z = 0.01006$

The solution of these simultaneous linear difference equations may be obtained by writing the differences in the form

$$\xi_n = x_n - x_{n-1} = A\lambda^n$$
$$\eta_n = y_n - y_{n-1} = B\lambda^n$$
$$\zeta_n = z_n - z_{n-1} = C\lambda^n$$

where A, B, C are constants, and λ satisfies the equations

$$Aa_1\lambda + Bb_1 + Cc_1 = 0$$
$$Aa_2\lambda + Bb_2\lambda + Cc_2 = 0$$
$$Aa_3 + Bb_3 + Cc_3 = 0.$$

Hence λ is given by the " characteristic " equation

$$\begin{vmatrix} a_1\lambda, & b_1, & c_1 \\ a_2\lambda, & b_2\lambda, & c_2 \\ a_3, & b_3, & c_3 \end{vmatrix} = 0$$

Thus

$$\xi_n = A_1\lambda_1^n + A_2\lambda_2^n$$
$$\eta_n = B_1\lambda_1^n + B_2\lambda_2^n$$
$$\zeta_n = C_1\lambda_1^n + C_2\lambda_2^n$$

where λ_1, λ_2 are the roots of the characteristic equation. When λ_1, λ_2 are known the constants A_1, A_2, B_1, B_2, C_1, C_2 can be found from the equations

$$\xi_1 = x_1 - x_0 = x_1 = A_1\lambda_1 + A_2\lambda_2$$
$$\xi_2 = x_2 - x_1 = A_1\lambda_1^2 + A_2\lambda_2^2$$

and so on.

Now

$$\begin{aligned} x_n &= x_1 + x_2 - x_1 + x_3 - x_2 + \ldots + x_n - x_{n-1} \\ &= \xi_1 + \xi_2 + \xi_3 \ldots + \xi_n \\ &= A_1 \sum_{r=1}^{r=n} \lambda_1^r + A_2 \sum_{r=1}^{r=n} \lambda_2^r \end{aligned}$$

and so x_n will be convergent provided λ_1, λ_2 are numerically less than unity if real, or if they are imaginary provided that their modulus is less than unity.

The foregoing is evidently general whatever the number of variables.

The tabular method may be seen to give successively in the x column a_1x_1, $a_1(x_2-x_1)$, $a_1(x_3-x_2)$, etc. Similarly for the columns for the other variables. It is thus essentially a convenient organisation of the iteration procedure, due advantage being taken of iterating with changes in the current values of the unknowns instead of with their total current values.

So far as stable structures are concerned the simultaneous equations are usually of the requisite form for convergency of the process.

5. Analysis of a Three-Bay Braced Plane Frame

As an example of the application of the method to a structure consider the case of the three-bay braced frame illustrated in Fig. 3.

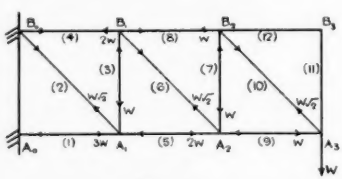


FIG. 3.

We will assume that all the members are uniform, of equal cross section and have the same elastic properties. For the purpose of finding the linear

deflections of the joints we assume in the first place that the joints are pin-jointed. We thus obtain

$$X_{A1}=3\,Wx_{11},\ X_{A2}=5\,Wx_{11},\ X_{A3}=6\,Wx_{11},$$
$$Y_{A1}=5.828\,Wx_{11},\ Y_{A2}=16.656\,Wx_{11},\ Y_{A3}=29.484\,Wx_{11},$$
$$X_{B1}=-2\,Wx_{11},\ X_{B2}=-3\,Wx_{11},\ X_{B3}=-3\,Wx_{11},$$
$$Y_{B1}=6.828\,Wx_{11},\ Y_{B2}=17.656\,Wx_{11},\ Y_{B3}=29.484\,Wx_{11},$$

where x_{11} is the compression (or extension) of all members except the diagonals, due to unit load acting along those members.

Let us further assume that the member A_1A_2 is carrying an end load equal to its Euler failing load as a pin-jointed strut then

$$a_5=(l/2)\sqrt{(2W/EI)}=\pi/2 \text{ radians},$$

l being the length of the member.

Hence for the compression members:—

a (radians)	$1/\phi\,(a/2)$	$\phi\,(a)/\psi\,(a)$	$f\,(a)/\psi\,(a)$
$a_1=(l/2)\sqrt{(3W/EI)}=1.92$ ...	0.73	0.35	1.4
$a_3=(l/2)\sqrt{(W/EI)}=1.11$ ...	0.92	0.85	1.03
$a_5=(l/2)\sqrt{(2W/EI)}=\pi/2$ ...	0.82	0.63	1.2
$a_7=(l/2)\sqrt{(W/EI)}=1.11$ ...	0.92	0.85	1.03
$a_9=(l/2)\sqrt{(W/EI)}=1.11$ ...	0.92	0.85	1.03
$a_{11}=0$	1.0	1.0	1.0

For the tension members:—

a (radians)	$1/\Phi\,(a/2)$	$\Phi\,(a)/\Psi\,(a)$	$F\,(a)/\Psi\,(a)$
$a_2=\frac{1}{2}(l\sqrt{2})\sqrt{(\sqrt{2}W/EI)}=1.87$ ...	1.25	1.4	0.81
$a_4=(l/2)\sqrt{(2W/EI)}=\pi/2$	1.2	1.3	0.92
$a_6=\frac{1}{2}(l\sqrt{2})\sqrt{(\sqrt{2}W/EI)}=1.87$ ...	1.25	1.4	0.81
$a_8=(l/2)\sqrt{(W/EI)}=1.11$	1.11	1.2	0.96
$a_{10}=\frac{1}{2}(l\sqrt{2})\sqrt{(\sqrt{2}W/EI)}=1.87$ ...	1.25	1.4	0.81
$a_{12}=0$	1.0	1.0	1.0

Let M_{f1}, M_{f2} ... M_{f12} be the end fixing moments which would be required to maintain the various members in their displaced positions but without rotation of the joints. Then

$$M_{f1}=-(6EI/l^2)\,Y_{A1}\,(1/\phi a_1/2)=-6\,(5.828)\,(0.73\,\lambda)=-25.53\,\lambda$$
$$M_{f2}=-(6EI/2l^2)\,(1/\sqrt{2})\,(8.828)\,(1.25\,Wx_{11})=-23.41\,\lambda$$
$$M_{f3}=-(6EI/l^2)\,(5)\,(0.92\,Wx_{11})=-27.6\,\lambda$$
$$M_{f4}=-(6EI/l^2)\,(6.828)\,(1.2\,Wx_{11})=-49.16\,\lambda$$
$$M_{f5}=-(6EI/l^2)\,(10.828)\,(0.82\,Wx_{11})=-53.27\,\lambda$$
$$M_{f6}=-(6EI/2l^2)\,(1/\sqrt{2})\,(16.828)\,(1.25\,Wx_{11})=-44.62\,\lambda$$
$$M_{f7}=-(6EI/l^2)\,(8)\,(0.92\,Wx_{11})=-44.16\,\lambda$$
$$M_{f8}=-(6EI/l^2)\,(10.828)\,(1.11\,Wx_{11})=-72.11\,\lambda$$
$$M_{f9}=-(6EI/l^2)\,(12.828)\,(0.92\,Wx_{11})=-70.81\,\lambda$$
$$M_{f10}=-(6EI/2l^2)\,(1/\sqrt{2})\,(20.828)\,(1.25\,Wx_{11})=-55.23\,\lambda$$
$$M_{f11}=-(6EI/l^2)\,(9)\,(1\,Wx_{11})=-54\,\lambda$$
$$M_{f12}=-(6EI/l^2)\,(11.828)\,(1\,Wx_{11})=-70.97\,\lambda$$

where $\lambda=Wk^2/l$.

Considering the equilibrium of the moments at the joints we obtain the following equations

$$M_{f1}+M_{f2}+M_{f3}+M_{f5}+(4EI/l)\,(0.35+1.4/\sqrt{2}+0.85+0.63)\,\phi_{A1}$$
$$+(2EI/l)\,(1.03\,\phi_{B1}+1.2\,\phi_{A2})=0\ (A_1)$$
$$M_{f3}+M_{f4}+M_{f6}+M_{f8}+(4EI/l)\,(0.85+1.3+1.4/\sqrt{2}+1.2)\,\phi_{B1}$$
$$+(2EI/l)\,[1.03\,\phi_{A1}+(0.81/\sqrt{2})\,\phi_{A2}+0.96\,\phi_{B2}]=0\ (B_1)$$
$$M_{f5}+M_{f6}+M_{f7}+M_{f9}+(4EI/l)\,(0.63+1.4/\sqrt{2}+0.85+0.85)\,\phi_{A2}$$
$$+(2EI/l)\,[1.2\,\phi_{A1}+(0.81/\sqrt{2})\,\phi_{B1}+1.03\,\phi_{B2}+1.03\,\phi_{A3}]=0\ (A_2)$$

$$M_{f7}+M_{f8}+M_{f10}+M_{f12}+(4EI/l)\ (0.85+1.2+1.4/\sqrt{2}+1)\ \phi_{B2}$$
$$+(2EI/l)\ [1.03\ \phi_{A2}+0.96\ \phi_{B1}+(0.81/\sqrt{2})\ \phi_{A3}+1\times\phi_{B3}]=0\ (B_2)$$
$$M_{f9}+M_{f10}+M_{f11}+(4EI/l)\ (0.85\times 1.4/\sqrt{2}+1)\ \phi_{A3}$$
$$+(2EI/l)\ [1.03_{\ A2}+(0.81/\sqrt{2})\ \phi_{B2}+1\times\phi_{B3}]=0\ (A_3)$$
$$M_{f11}+M_{f12}+(4EI/l)\ (1+1)\ \phi_{B3}+(2EI/l)\ (\phi_{B2}+\phi_{A3})=0\ (B_3).$$

These equations become,

Coefficients of						Constants.
ϕ_{A1}	ϕ_{B1}	ϕ_{A2}	ϕ_{B2}	ϕ_{A3}	ϕ_{B3}	
11.32	2.06	2.4	0	0	0	129.8 μ
2.06	17.4	1.146	1.92	0	0	193.49 μ
2.4	1.146	13.32	2.06	2.06	0	212.86 μ
0	1.92	2.06	16.2	1.146	2	240.47 μ
0	0	2.06	1.146	11.4	2	180.04 μ
0	0	0	2	2	8	124.97 μ

where $\mu=Wk^2/EI$.

NOTE.—The symmetry of these equations about the leading diagonal may be explained by Lord Rayleigh's reciprocal relations. This reciprocity will be evident in the other cases which will be dealt with later.

The proportions for distribution in the appropriate columns are

Ratios	1	2	3	4	5	6
a_r/a_1 $(r=2, 3, 4, 5, 6)$ ...	—	0.182	0.212	0	0	0
b_r/b_2 $(r=1, 3, 4, 5, 6)$ ...	0.118	—	0.0659	0.110	0	0
c_r/c_3 $(r=1, 2, 4, 5, 6)$ ...	0.180	0.0860	—	0.155	0.155	0
d_r/d_4 $(r=1, 2, 3, 5, 6)$ ...	0	0.118	0.127	—	0.0707	0.123
e_r/e_5 $(r=1, 2, 3, 4, 6)$ ...	0	0	0.181	0.100	—	0.175
f_r/f_6 $(r=1, 2, 3, 4, 5)$ ...	0	0	0	0.25	0.25	—

The solution then proceeds as in Table II, thus we have:—

$$11.32\ \phi_{A1}=87.35\ \mu\ \therefore\ \phi_{A1}=7.71\ \mu$$
$$17.4\ \phi_{B1}=145.51\ \mu\ \therefore\ \phi_{B1}=8.36\ \mu$$
$$13.32\ \phi_{A2}=140.43\ \mu\ \therefore\ \phi_{A2}=10.54\ \mu$$
$$16.2\ \phi_{B2}=169.61\ \mu\ \therefore\ \phi_{B2}=10.47\ \mu$$
$$11.4\ \phi_{A3}=125.76\ \mu\ \therefore\ \phi_{A3}=11.05\ \mu$$
$$8\ \phi_{B3}=82.11\ \mu\ \therefore\ \phi_{B3}=10.26\ \mu$$

On inserting these values in the original equations we obtain the following:—

129.87 μ, 193.57 μ, 212.80 μ, 240.59 μ, 179.99 μ, 125.15 μ.

These values are sufficiently close for practical purposes for the particular problem. If, however, closer values are required then we may proceed as follows. Let Φ_{A1}, Φ_{B1}, etc., be the true values and let $\Phi_{A1}=\phi_{A1}+\epsilon_{A1}$ where ϕ_{A1} is the value found. On substituting these values in the original equations we obtain a new set for ϵ_{A1}, ϵ_{B1}, etc., as follows:—

$$11.32\ \epsilon_{A1}+2.06\ \epsilon_{B1}+2.4\ \epsilon_{A2}+0+0+0=-0.07\ \mu$$
$$2.06\ \epsilon_{A1}+17.4\ \epsilon_{B1}+1.146\ \epsilon_{A2}+1.92\ \epsilon_{B2}+0+0=-0.08\ \mu$$
$$2.4\ \epsilon_{A1}+1.146\ \epsilon_{B1}+13.32\ \epsilon_{A2}+2.06\ \epsilon_{B2}+2.06\ \epsilon_{A3}+0=+0.06\ \mu$$
$$0+1.92\ \epsilon_{B1}+2.06\ \epsilon_{A2}+16.2\ \epsilon_{B2}+1.146\ \epsilon_{A3}+2\ \epsilon_{B3}=-0.12\ \mu$$
$$0+0+2.06\ \epsilon_{A2}+1.146\ \epsilon_{B2}+11.4\ \epsilon_{A3}+2\ \epsilon_{B3}=+0.05\ \mu$$
$$0+0+0+2\epsilon_{B2}+2\ \epsilon_{A3}+8\ \epsilon_{B3}=-0.18\ \mu.$$

We may now multiply the constants by, say, 1,000 and proceed to solve as before, of course dividing the results by 1,000. By this means we may obtain a very close correction.

TABLE II.

+129.8	+193.49	+212.86	+240.47	180.04	+124.97
0	−23.62	−27.52	0	0	0
−20.04	+169.87	−11.19	−18.69	0	0
−31.35	−14.97	+174.14	−26.99	−26.99	0
0	−22.98	−24.74	+194.79	−13.77	−23.96
0	0	−25.21	−13.90	+139.28	−24.37
0	0	0	−19.16	−19.16	+76.64
−51.39	+9.35	+10.89	0	0	0
+3.38	−28.61	+1.88	+3.14	0	0
+6.69	+3.20	−37.18	+5.76	+5.76	0
0	+2.85	+3.07	−24.16	+1.71	+2.97
0	0	+2.12	+1.17	−11.69	+2.04
0	0	0	−1.25	−1.25	+5.01
+10.07	−1.83	−2.13	0	0	0
−0.50	+4.22	−0.28	−0.46	0	0
−0.50	−0.24	+2.78	−0.43	−0.43	0
0	+0.11	+0.12	−0.97	+0.07	+0.12
0	0	+0.29	+0.16	−1.61	+0.28
0	0	0	−0.10	−0.10	+0.43
−1.00	+0.18	+0.21	0	0	0
−0.01	+0.05	—	−0.01	0	0
−0.11	−0.05	+0.63	−0.10	−0.10	0
0	+0.01	—	−0.05	—	—
0	0	+0.03	+0.02	−0.20	+0.03
0	0	0	−0.01	−0.01	+0.03
−0.12	+0.02	+0.03	0	0	0
—	−0.02	—	—	—	—
−0.01	—	+0.06	−0.01	−0.01	0
—	—	—	0	—	—
—	—	—	—	−0.02	—
—	—	—	—	—	0
+87.35	+145.51	+140.43	+169.61	+125.76	+82.11

6. Analysis of a Girder-Braced Hexagonal Ring

As another example consider the case of the braced hexagonal ring illustrated in Fig. 4.

For the purpose of this problem we will assume that all the members are uniform and are of the same section, but that the Young's modulus of the members of the ring (shown by thick lines in the Fig.) is four times that for the bracing members (shown by faint lines in the Fig.). It will also be assumed that all the joints are rigid.

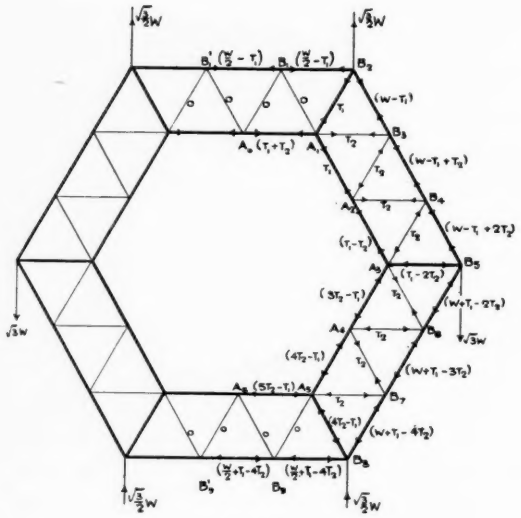


FIG. 4.

To find the loading actions in the members due to the external loads shown in the figure we make the assumption (in the first place) that the joints are pin-jointed. We thus find that there are two unknowns in the internal loads which we designate T_1, T_2. Applying Castigliano's theorem of least work we have

$$\begin{aligned} 2E = 16\,T_2^2 x_{11} + [&4\,T_1^2 + 2\,(T_1+T_2)^2 + 2\,(T_1-T_2)^2 + 2\,(T_1-2\,T_2)^2 \\ &+ 4\,(4\,T_2-T_1)^2 + 2\,(5\,T_2-T_1)^2 + 3\,(W/2-T_1)^2 \\ &+ 3\,(W/2+T_1-4\,T_2)^2 + 2\,(W-T_1)^2 + 2\,(W-T_1+T_2)^2 \\ &+ 2\,(W-T_1+2\,T_2)^2 + 2\,(W+T_1-2\,T_2)^2 \\ &+ 2\,(W+T_1-3\,T_2)^2 + 2\,(W+T_1-4\,T_2)^2]\,x_{22} \end{aligned}$$

where x_{11} refers to a bracing member and x_{22} to a member of the ring.

Now

$$\partial E/\partial T_1 = (36\,T_1 - 72\,T_2)\,x_{22} = 0$$
$$\therefore T_1 = 2\,T_2$$

and

$$\partial E/\partial T_2 = 16\,T_2 x_{11} + (-18\,W - 72\,T + 260\,T)\,x_{22} = 0$$

which since $x_{22} = 4x_{11}$ becomes

$$-18\,W - 72\,T_1 + 324\,T_2 = 0.$$

Hence $T_1 = \frac{1}{5}\,W$, $T_2 = 1/10\,W$.

Taking the point A_0 as origin we find that in consequence of the axial loads in the various members that the displacements of the various joints are as follows:—

$$X_{A1} = -0.3\,Wx_{22},\ Y_{A1} = 0;\ X_{B1} = -0.15\,Wx_{22},\ Y_{B1} = +\frac{\sqrt{3}}{20}\,Wx_{22};$$

$$X_{B2} = -0.45\,Wx_{22},\ Y_{B2} = -\frac{0.25}{\sqrt{3}}\,Wx_{22};\ X_{B3} = -0.7\,Wx_{22},\ Y_{B3} = +\frac{1.1}{\sqrt{3}}\,Wx_{22};$$

$$X_{A2} = -0.55\,Wx_{22},\ Y_{A2} = +\frac{\sqrt{3}}{20}\,Wx_{22};\ X_{B4} = -0.95\,Wx_{22},\ Y_{B4} = +\frac{2.65}{\sqrt{3}}\,Wx_{22};$$

$$X_{A3} = 0,\ Y_{A3} = 0.3\sqrt{3}\,Wx_{22};\ X_{B5} = 0,\ Y_{B5} = +\frac{5.6}{\sqrt{3}}\,Wx_{22};$$

$X_{A4}=+0.55\,Wx_{22}$, $Y_{A4}=+\frac{\sqrt{3}}{20}Wx_{22}$; $X_{B6}=+0.95Wx_{22}$, $Y_{B6}=+\frac{2.65}{\sqrt{3}}Wx_{22}$;

$X_{A5}=+0.3\,Wx_{22}$, $Y_{A5}=0$; $X_{B7}=0.7\,Wx$, $Y_{B7}=+\frac{1.1}{\sqrt{3}}Wx_{22}$;

$X_{B8}=+0.45Wx_{22}$, $Y_{B8}=-\frac{0.25}{\sqrt{3}}Wx_{22}$; $X_{B9}=0.15\,Wx_{22}$, $Y_{B9}=+\frac{\sqrt{3}}{20}Wx_{22}$;

$X_{A6}=0$, $Y_{A6}=0$.

With these values we find when end load deflection effects are neglected that the fixing moments for the various members are

B'_1B_1, B'_9B_9	...	...	0
B_1B_2, B_9B_8	...	...	$+0.231\,\lambda$
B_2B_3, B_8B_7	...	...	$-0.173\,\lambda$
B_3B_4, B_7B_6	...	...	$-0.231\,\lambda$
B_4B_5, B_6B_5	...	...	$-1.674\,\lambda$
A_0A_1, A_6A_5	...	...	0
A_1A_2, A_5A_4	...	...	$-0.173\,\lambda$
A_2A_3, A_4A_3	...	...	$-0.693\,\lambda$
A_0B_1, B_9A_6	...	...	$-0.173\,\lambda$
B_1A_1, B_9A_5	...	...	$+0.173\,\lambda$
A_1B_2, B_8A_5	...	...	$-0.0577\,\lambda$
A_1B_3, A_5B_7	...	...	$-0.635\,\lambda$
A_2B_3, A_4B_7	...	...	$+0.404\,\lambda$
A_2B_4, A_6B_6	...	...	$-1.443\,\lambda$
A_3B_4, A_3B_6	...	...	$-1.328\,\lambda$
A_3B_5	...	...	$-2.713\,\lambda$

where $\lambda=(6EI/l^2)\,Wx_{22}=6Wk^2/l$.

By considering the equilibrium of the moments at all the joints with end load deflection effects neglected for simplicity, we obtain the following fourteen simultaneous equations for determining the angular rotations at the joints where

$$\mu=6W/EA.$$

Co-efficients of

Joint.	ϕ_{B1}	ϕ_{B2}	ϕ_{A1}	ϕ_{B3}	ϕ_{A2}	ϕ_{B4}	ϕ_{A3}	ϕ_{B5}	ϕ_{B6}	ϕ_{A4}	ϕ_{B7}	ϕ_{A5}	ϕ_{B8}	ϕ_{B9}	Constants
B_1	8	2	·5	0	0	0	0	0	0	0	0	0	0	0	$-0.231\,\mu$
B_2	2	12	2	2	0	0	0	0	0	0	0	0	0	0	$+0.115\,\mu$
A_1	·5	2	14	·5	2	0	0	0	0	0	0	0	0	0	0
B_3	0	2	·5	10	·5	2	0	0	0	0	0	0	0	0	$+0.462\,\mu$
A_2	0	0	2	·5	10	·5	2	0	0	0	0	0	0	0	$+0.780\,\mu$
B_4	0	0	0	2	·5	10	·5	2	0	0	0	0	0	0	$+2.598\,\mu$
A_3	0	0	0	0	2	·5	14	2	·5	2	0	0	0	0	$+4.763\,\mu$
B_5	0	0	0	0	0	2	2	12	2	0	0	0	0	0	$+6.061\,\mu$
B_6	0	0	0	0	0	0	·5	2	10	·5	2	0	0	0	$+2.598\,\mu$
A_4	0	0	0	0	0	0	2	0	·5	10	·5	2	0	0	$+0.780\,\mu$
B_7	0	0	0	0	0	0	0	0	2	·5	10	·5	2	0	$+0.462\,\mu$
A_5	0	0	0	0	0	0	0	0	0	2	·5	14	2	·5	0
B_8	0	0	0	0	0	0	0	0	0	0	2	2	12	2	$+0.115\,\mu$
B_9	0	0	0	0	0	0	0	0	0	0	0	·5	2	8	$-0.231\,\mu$

The solution of these simultaneous equations is given in Table III.

7. The Plane Frame with Deformation Normal to the Plane of the Frame

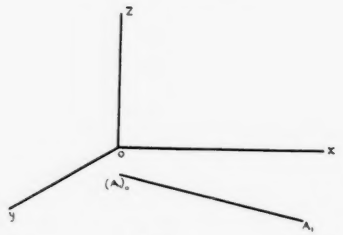


Fig. 5.

Referring to Fig. 5, let $(A_1)_o A_1$ be a member of a frame in the plane of xOy. Let $Z_{(A1)o}$, Z_{A1} be the displacements of the points $(A_1)_o$, A_1 normal to the plane xOy and measured positive vertically downwards and let $\theta_{(A1)o}$, $\phi_{(A1)o}$ be the angular rotations of the joint at $(A_1)_o$ about the axis through $(A_1)_o$ parallel to the axes Ox, Oy respectively. Similarly, let θ_{A1}, ϕ_{A1} refer to the point A_1. Let λ_1 be the angle which $(A_1)_o A_1$ makes with Ox. Then as a result there will be

(i) A torsion in the member $(A_1)_o A_1$ of amount

$$[\theta_{A1}-\theta_{(A1)o}]\cos\lambda_1+[\phi_{A1}-\phi_{(A1)o}]\sin\lambda_1;$$

(ii) An angular rotation

$$\phi_{A1}\cos\lambda_1-\theta_{A1}\sin\lambda_1$$

at A_1 about an axis through A_1 in the plane xOy and normal to $(A_1)_o A_1$;

(iii) And a similar angular rotation

$$\phi_{(A1)o}\cos\lambda_1-\theta_{(A1)o}\sin\lambda_1$$

at the point $(A_1)_o$.

Hence so far as the member $(A_1)_o A_1$ is concerned, if this be supposed uniform and carries *inter alia* a uniform loading of w_1 per unit length, then it may be shown that

$$M_1=-\frac{6e_1}{l_1}\frac{1}{\phi(a_1/2)}\delta_1+\frac{w_1l_1^2}{12}\psi(a_1/2)+4e_1\frac{\varphi(a_1)}{\psi(a_1)}[\phi_{A1}\cos\lambda_1-\theta_{A1}\sin\lambda_1]$$
$$+2e_1\frac{f(a_1)}{\psi(a_1)}[\phi_{(A1)o}\cos\lambda_1-\theta_{(A1)o}\sin\lambda_1]$$

$$(M_1)_o=-\frac{6e_1}{l_1}\frac{1}{\phi(a_1/2)}\delta_1-\frac{w_1l_1^2}{12}\phi(a_1/2)+2e_1\frac{f(a_1)}{\psi(a_1)}[\phi_{A1}\cos\lambda_1-\theta_{A1}\sin\lambda_1]$$
$$+4e_1\frac{\phi(a_1)}{\psi(a_1)}[\phi_{(A1)o}\cos\lambda_1-\theta_{(A1)o}\sin\lambda_1]$$

where $\delta_1=Z_{A1}-Z_{(A1)o}$

$e_1=E_1I_1/l_1$

and the functions of a_1 are due to the end load (taken compressive) in the member.

There will also be a torque in the member of amount

$$T_1=c_1[\{\theta_{A1}-\theta_{(A1)o}\}\cos\lambda_1+\{\phi_{A1}-\phi_{(A1)o}\}\sin\lambda_1]$$

where c_1 = torsional stiffness of the member such that for a uniform circular rod

$$c_1=C_1(I_1)_p/l_1$$

where $(I_1)_p$ = polar moment of inertia and C_1 = modulus of rigidity.

$8\,\phi_{B1}$	$12\,\phi_{B2}$	$14\,\phi_{A1}$	$10\,\phi_{B3}$	
−231	+115	0	+462	
	+57.75	+14.44		
−28.79	+172.75	−28.79	−28.79	
+0.51	+2.05	−14.35	+0.51	
	−86.74	−21.69	+433.72	
		−152.07	−38.02	
			+494.65	
−28.28	+7.07	+1.77		
+12.94	−77.62	+12.94	+12.94	
	+22.72	−159.05	+5.68	
	+102.81	+25.70	−514.05	
		+143.26	+35.82	
			+168.50	
+18.62	−4.66	−1.16		
−20.14	+120.87	−20.14	−20.14	
−5.27	−21.09	+147.66	−5.27	
	−35.78	−8.95	+178.91	
		−23.22	−5.81	
			+1.42	
−25.41	+6.35	+1.59		
+8.42	−50.52	+8.42	+8.42	
+0.80	+3.18	−22.16	+0.80	
	−0.97	−0.24	+4.83	
		−1.65	−0.41	
			+0.21	
−9.22	−2.31	−0.58		
+0.02	−0.10	+0.02	+0.02	
+0.09	+0.35	−2.45	+0.09	
	+0.02	—	−0.09	
		−0.20	−0.05	
			+0.01	
+0.11	−0.03	−0.01		
−0.06	+0.34	−0.06	−0.06	
+0.01	+0.04	−0.27	+0.01	
	+0.02	—	−0.09	
		−0.04	−0.01	
			−0.02	
−0.05	+0.01	—		
−0.01	+0.07	−0.01	−0.01	
—	+0.01	−0.05	—	
	+0.01	—	+0.04	
		−0.01	—	
			—	
Algebraic sum				
−256.80	+165.81	−50.68	+103.19	+

Hence since all quantities are $10^3 \times$ their true values

$\phi_{B1} =$	$\phi_{B2} =$	$\phi_{A1} =$	$\phi_{B3} =$	
$-32.10 \times 10^{-3}\,\mu$	$+13.82 \times 10^{-3}\,\mu$	$-3.62 \times 10^{-3}\,\mu$	$+10.32 \times 10^{-3}\,\mu$	+16.

TABLE III.

$10\,\phi_{A2}$	$10\,\phi_{B1}$	$14\,\phi_{A3}$	$12\,\phi_{B5}$	$10\,\phi_{B6}$
+780	+2598	+4763	+6061	+2598
+2.05				
−21.67	−86.74			
+760.36	−38.02	−152.07		
−123.66	+2473.24	−123.66	−494.65	
−641.04	−160.26	+4487.27	−641.04	−160.26
	−820.88	−820.88	+4925.31	−820.88
		−80.84	−323.37	+1616.86
+22.72		−11.62	0	−2.91
+25.70	+102.81			−27.14
−716.28	+35.82	+143.26		
+42.12	−842.52	+42.12	+168.50	
+104.00	+26.00	−727.96	+104.00	+26.00
	+8.48	+8.48	−50.87	+8.48
		−0.22	−0.89	+4.43
−21.09		−19.92	0	−4.98
−8.95	−35.78			+4.06
+116.08	−5.81	−23.22		
+0.36	−7.11	+0.36	+1.42	
+4.93	+1.23	−34.52	+4.93	+1.23
	−0.91	−0.91	+5.46	−0.91
		+0.03	+0.12	−0.60
+3.18		−1.73	0	−0.43
−0.24	−0.97			+2.20
+8.23	−0.41	−1.65		
+0.05	−1.06	+0.05	+0.21	
+0.60	+0.15	−4.21	+0.60	+0.15
	−0.16	−0.16	+0.93	−0.16
		−0.09	−0.35	+1.76
+0.35		−0.55	0	+0.14
—	+0.02			+0.23
+1.00	−0.05	−0.20		
—	−0.04	—	+0.01	
+0.14	+0.04	−1.00	+0.14	+0.04
	+0.03	+0.03	−0.20	+0.03
		−0.01	−0.03	+0.16
+0.04		−0.08	0	−0.02
—	+0.02			+0.02
+0.18	−0.01	−0.04		
—	+0.08	—	−0.02	
+0.02	—	−0.10	+0.02	—
	+0.01	+0.01	−0.03	+0.01
		—	—	+0.01
+0.01		−0.01	0	—
—	+0.01			—
+0.03	—	−0.01		
—	+0.02	—	—	
—	—	−0.01	—	—
+169.60	+1622.61	+3719.47	+4880.60	+1622.62
$\phi_{A2} = +16.96 \times 10^{-3}\,\mu$	$\phi_{B1} = +162.26 \times 10^{-3}\,\mu$	$\phi_{A3} = +265.70 \times 10^{-3}\,\mu$	$\phi_{B5} = +406.72 \times 10^{-3}\,\mu$	$\phi_{B6} = +162.26 \times 10^{-3}\,\mu$

ϕ_{B5}	$10\,\phi_{B6}$	$10\,\phi_{A}$
1	+ 2598	+ 780
4.65		
1.04	− 160.26	− 640.0
5.31	− 820.88	
3.37	+ 1616.86	− 80.8
0	− 2.91	+ 58.1
	− 27.14	− 6.7
		+ 2.6
8.50		
4.00	+ 26.00	+ 104.0
0.87	+ 8.48	
0.89	+ 4.43	− 0.2
0	− 4.98	+ 99.6
	+ 4.06	+ 1.0
		+ 2.6
1.42		
4.93	+ 1.23	+ 4.9
5.46	− 0.91	
0.12	− 0.60	+ 0.0
0	− 0.43	+ 8.6
	+ 2.20	+ 0.3
		+ 1.6
0.21		
0.60	+ 0.15	+ 0.6
0.93	− 0.16	
0.35	+ 1.76	− 0.0
0	+ 0.14	+ 2.7
	+ 0.23	+ 0.0
		+ 0.2
0.01		
0.14	+ 0.04	+ 0.1
0.20	+ 0.03	
0.03	+ 0.16	− 0.0
0	− 0.02	+ 0.4
	+ 0.02	—
		+ 0.0
0.02		
0.02	—	+ 0.0
0.03	+ 0.01	
—	+ 0.01	—
0	—	+ 0.0
	—	—
		—
—	—	
0.60	+ 1622.62	+ 169.0
=	ϕ_{B6} =	ϕ_{A1} =
$\times 10^{-3}\,\mu$	$162.26 \times 10^{-3}\,\mu$	$+ 16.96 \times$

$10\,\phi_{A4}$	$10\,\phi_{B7}$	$14\,\phi_{A5}$	$12\,\phi_{B8}$	$8\,\phi_{B9}$
+780	+462	0	+115	−231
−640.64				
−80.84	−323.37			
+58.12	−2.91	−11.62		
−6.79	+135.72	−6.79	−27.14	
+2.63	+0.66	−18.41	+2.63	+0.66
	−15.08	−15.08	+90.49	−15.08
+104.00		+15.34	+61.36	−245.42
−0.22	−0.89			
+99.62	−4.98	−19.92		
+1.02	−20.29	+1.02	+4.06	
+2.68	+0.67	−18.64	+2.68	+0.67
	−11.35	−11.35	+68.10	−11.35
+4.93				−10.68
+0.03	+0.12			
+8.66	−0.43	−1.73		
+0.55	−10.99	+0.55	+2.20	
+1.69	+0.42	−11.86	+1.69	+0.42
	−1.09	−1.09	+6.56	−1.09
+0.60		+0.04	+0.17	−0.67
−0.09	−0.35			
+2.75	−0.14	−0.55		
+0.06	−1.16	+0.06	+0.23	
+0.22	+0.06	−1.54	+0.22	+0.06
	−0.10	−0.10	+0.62	−0.10
+0.14		—	+0.01	−0.04
−0.01	−0.03			
+0.41	−0.02	−0.08		
—	−0.09	—	+0.02	
+0.03	+0.01	−0.18	+0.03	+0.01
	−0.01	−0.01	+0.06	−0.01
+0.02		—	—	—
—	—			
+0.05	—	−0.01		
—	—	—	—	
—	—	−0.02	—	—
	—	—	—	—
—		—	—	—
+169.61	+103.19	−50.66	+165.81	−256.81
$\phi_{A4} =$	$\phi_{B7} =$	$\phi_{A5} =$	$\phi_{B8} =$	$\phi_{B9} =$
$+16.96 \times 10^{-3}\ \mu$	$+10.32 \times 10^{-3}\ \mu$	$-3.62 \times 10^{-3}\ \mu$	$+13.82 \times 10^{-3}\ \mu$	$-32.10 \times 10^{-3}\ \mu$

The moments and the torque are reckoned positive clockwise from the point of view of the action of the joints on the member.

At the point A_1 of the member $(A_1)_0 A_1$ we therefore have

$$M_{x1} = -M_1 \sin\lambda_1 + T_1 \cos\lambda_1$$
$$M_{y1} = M_1 \cos\lambda_1 + T_1 \sin\lambda_1$$

Similarly

$$(M_{x1})_0 = -(M_1)_0 \sin\lambda_1 - T_1 \cos\lambda_1$$
$$(M_{y1})_0 = (M_1)_0 \cos\lambda_1 - T_1 \sin\lambda_1$$

Hence

$$M_{x1} = \frac{6e_1}{l_1}\frac{1}{\phi(a_1/2)}\delta_1 \sin\lambda_1 - \frac{w_1 l_1^2}{12}\phi(a_1/2)\sin\lambda_1$$
$$+\left[4e_1\frac{\phi(a_1)}{\psi(a_1)}\sin^2\lambda_1 + c_1\cos^2\lambda_1\right]\theta_{A1}$$
$$-\left[4e_1\frac{\varphi(a_1)}{\psi(a_1)} - c_1\right](\sin\lambda_1\cos\lambda_1)\,\phi_A + \left[2e_1\frac{f(a_1)}{\psi(a_1)}\sin^2\lambda_1 - c_1\cos^2\lambda_1\right]\theta_{(A1)0}$$
$$-\left[2e_1\frac{f(a_1)}{\psi(a_1)} + c_1\right](\sin\lambda_1\cos\lambda_1)\,\phi_{(A1)0}$$

and $$M_{y1} = -\frac{6e_1}{l_1}\frac{1}{\phi(a_1/2)}\delta_1\cos\lambda_1 + \frac{w_1 l_1^2}{12}\phi(a_1/2)\cos\lambda_1$$
$$-\left[4e_1\frac{\varphi(a_1)}{\psi(a_1)} - c_1\right](\sin\lambda_1\cos\lambda_1)\,\theta_{A1}$$
$$+\left[4e_1\frac{\varphi(a_1)}{\psi(a_1)}\cos^2\lambda_1 + c_1\sin^2\lambda_1\right]\phi_{A1} - \left[2e_1\frac{f(a_1)}{\psi(a_1)} + c_1\right](\sin\lambda_1\cos\lambda_1)\,\theta_{(A1)0}$$
$$+\left[2e\frac{f(a_1)}{\psi(a_1)}\cos^2\lambda_1 - c_1\sin^2\lambda_1\right]\phi_{(A1)0}$$

Similarly

$$(M_{x1})_0 = \frac{6e_1}{l_1}\frac{1}{\phi(a_1/2)}\delta_1\sin\lambda_1 + \frac{w_1 l_1^2}{12}\phi(a_1)\sin\lambda_1$$
$$+\left[2e_1\frac{f(a_1)}{\psi(a_1)}\sin^2\lambda_1 - c_1\cos^2\lambda_1\right]\theta_{A1}$$
$$-\left[2e\frac{f(a_1)}{\psi(a_1)} + c_1\right](\sin\lambda_1\cos\lambda_1)\,\phi_{A1} + \left[4e_1\frac{\phi(a_1)}{\psi(a_1)}\sin^2\lambda_1 + c_1\cos^2\lambda_1\right]\theta_{(A1)0}$$
$$-\left[4e_1\frac{\phi(a_1)}{\psi(a_1)} - c_1\right](\sin\lambda_1\cos\lambda_1)\,\phi_{(A1)0}$$
$$(M_{y1})_0 = -\frac{6e_1}{l_1}\frac{1}{\phi(a_1/2)}\delta_1\cos\lambda_1 - \frac{w_1 l_1^2}{12}\phi(a_1/2)\cos\lambda_1$$
$$-\left[2e_1\frac{f(a_1)}{\psi(a_1)} + c_1\right](\sin\lambda_1\cos\lambda_1)\,\theta_{A1}$$
$$+\left[2e_1\frac{f(a_1)}{\psi(a_1)}\cos^2\lambda_1 - c_1\sin^2\lambda_1\right]\phi_{A1} - \left[4e_1\frac{\phi(a_1)}{\psi(a_1)} - c_1\right](\sin\lambda_1\cos\lambda_1)\,\theta_{(A1)0}$$
$$+\left[4e_1\frac{\varphi(a_1)}{\psi(a_1)}\cos^2\lambda_1 + c_1\sin^2\lambda_1\right]\phi_{(A1)0}$$

The *downward* shear at A_1 for the member $(A_1)_0 A_1$ becomes

$$\{(M_1)_0 + M_1\}/l_1 + w_1 l_1/2$$

while the *upward* shear at $(A_1)_0$ becomes

$$\{(M_1)_0 + M_1\}/l_1 - w_1 l_1/2.$$

For the equilibrium at the joint

$$\Sigma M_x = 0,\ \Sigma M_y = 0,$$

it is being supposed that there are no external applied moments at the joint.

Also the total shear at the joint must balance the vertically applied weight (if any) at the joint.

As an example of the formation of the equations consider the rectangular braced plane frame with rigid joints shown in Fig. 6. The members are all taken to be of the same section and elastic properties. The side A_oB_o is encastered while at A_2 a load W is applied downwards and normal to the plane of the frame.

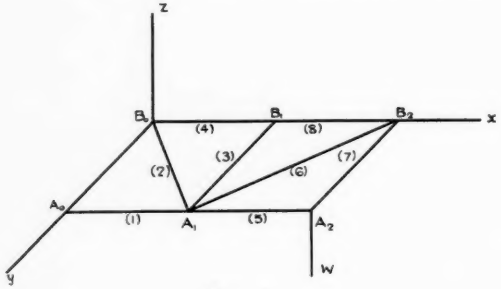


FIG. 6.

Let Z_A, θ_A, ϕ_A, be the displacements of the joint A_1 and similarly for the other joints. Then with the foregoing notation we have

Member A_oA_1 ($\lambda = 0$)

$$M_{x1} = c\theta_{A1}$$

$$M_1 = M_{y1} = -(6e/l)\,Z_{A1} + 4e\phi_{A1} \text{ at } A_1$$

$$(M_1)_o = (M_{y1})_o = -(6e/l)\,Z_{A1} + 2e\phi_{A1} \text{ at } A_o$$

Downward shear at A_1 for this member will therefore be

$$= -(12e/l^2)\,Z_{A1} + (6e/l)\,\phi_{A1}$$

Member B_oA_1 ($\lambda = 45°$)

$$M_{x2} = \frac{6e}{2l} Z_{A1} \frac{1}{\sqrt{2}} + \frac{(4e+c)}{2\sqrt{2}}\,\theta_{A1} - \frac{(4e-c)}{2\sqrt{2}}\,\phi_{A1} \text{ at } A_1$$

$$M_{y2} = -\frac{6e}{2l} Z_{A1} \frac{1}{\sqrt{2}} - \frac{(4e-c)}{2\sqrt{2}}\,\theta_{A1} + \frac{(4e+c)}{2\sqrt{2}}\,\phi_{A1} \text{ at } A_1$$

$$M_2 = -\frac{6e}{2l} Z_{A1} + \frac{4e}{\sqrt{2}}\,(\phi_{A1} - \theta_{A1})\,\frac{1}{\sqrt{2}} \text{ at } A_1$$

$$(M_2)_o = -\frac{6e}{2l} Z_{A1} + \frac{2e}{\sqrt{2}}\,(\phi_{A1} - \theta_{A1})\,\frac{1}{\sqrt{2}} \text{ at } B_o$$

Downward shear at A_1 for this member is therefore

$$= -\frac{6e}{\sqrt{2}\,l^2} Z_{A1} + \frac{3}{\sqrt{2}\,l}\,(\phi_{A1} - \theta_{A1})$$

Member A_1B_1 ($\lambda = -90°$)

$$(M_3)_o = (M_{x3})_o = -\frac{6e}{l}\,(Z_{B1} - Z_{A1}) + 4e\theta_{A1} + 2e\theta_{B1} \text{ at } A_1$$

$$M_3 = M_{x3} = -\frac{6e}{l}\,(Z_{B1} - Z_{A1}) + 2e\theta_{A1} + 4e\theta_{B1} \text{ at } B_1$$

Upward shear at A_1 for this member will therefore be

$$= -\frac{12e}{l^2}\,(Z_{B1} - Z_{A1}) + \frac{6e}{l}\,(\theta_{A1} + \theta_{B1})$$

This will also be the *downward* shear at B_1 for this member

$$(M_{y3})_o = c\,(\phi_{A1} - \phi_{B1}) \text{ at } A_1$$

Member A_1B_2 ($\lambda = -45°$)

$$(M_{x6})_0 = -\frac{6e}{2l}(Z_{B2}-Z_{A1})\frac{1}{\sqrt{2}} + \frac{(4e+c)}{2\sqrt{2}}\theta_{A1} + \frac{(4e-c)}{2\sqrt{2}}\phi_{A1} + \frac{(2e-c)}{2\sqrt{2}}\theta_{B1} + \frac{(2e+c)}{2\sqrt{2}}\phi_{B1} \text{ at } A_1$$

$$(M_{y6})_0 = -\frac{6e}{2l}(Z_{B2}-Z_{A1})\frac{1}{\sqrt{2}} + \frac{(4e-c)}{2\sqrt{2}}\theta_{A1} + \frac{(4e+c)}{2\sqrt{2}}\phi_{A1} + \frac{(2e+c)}{2\sqrt{2}}\theta_{B2} + \frac{(2e-c)}{2\sqrt{2}}\phi_{B2} \text{ at } A_1$$

$$M_6 = -\frac{6e}{2l}(Z_{B2}-Z_{A1}) + \frac{4e}{\sqrt{2}}(\phi_{B2}+\theta_{B2})\frac{1}{\sqrt{2}} + \frac{2e}{\sqrt{2}}(\phi_{A1}+\theta_{A1})\frac{1}{\sqrt{2}} \text{ at } B_2$$

$$(M_6)_0 = -\frac{6e}{2l}(Z_{B2}-Z_{A1}) + \frac{2e}{\sqrt{2}}(\phi_{B2}+\theta_{B2})\frac{1}{\sqrt{2}} + \frac{4e}{\sqrt{2}}(\phi_{A1}+\theta_{A1})\frac{1}{\sqrt{2}} \text{ at } A_1$$

Downward shear at B_2 for this member will therefore be

$$= -\frac{6e}{\sqrt{2}l^2}(Z_{B2}-Z_{A1}) + \frac{3e}{\sqrt{2}l}(\theta_{A1}+\phi_{A1}+\theta_{B2}+\phi_{B2})$$

This will also be the *upward* shear at A_1 for this member

Member A_1A_2 ($\lambda = 0$)

$$(M_{x5})_0 = c(\theta_{A1}-\theta_{A2}) \text{ at } A_1$$

$$M_5 = M_{y5} = -(6e/l)(Z_{A2}-Z_{A1}) + 4e\phi_{A2} + 2e\phi_{A1} \text{ at } A_2$$

$$(M_5)_0 = (M_{y5})_0 = -(6e/l)(Z_{A2}-Z_{A1}) + 2e\phi_{A2} + 4e\phi_{A1} \text{ at } A_1$$

Upward shear at A_1 for this member will therefore be

$$= -(12e/l^2)(Z_{A2}-Z_{A1}) + (6e/l)(\phi_{A1}+\phi_{A2})$$

This will also be the *downward* shear at A_2.

From the conditions of equilibrium at the joint A_1 we have

$$\Sigma M_x = 0,\ \Sigma M_y = 0, \text{ and total shear} = 0.$$

Hence we find

$$\left[(4+2\sqrt{2})e + (2+\frac{1}{\sqrt{2}})c\right]\theta_{A1} + \left[(2+\frac{1}{\sqrt{2}})e - \frac{1}{2\sqrt{2}}c\right]\theta_{B1} + \frac{(2e+c)}{2\sqrt{2}}\phi_{B1} - c\theta_{A2} + \frac{6(1+\frac{1}{\sqrt{2}})e}{l}Z_{A1} - \frac{3e}{l}Z_{B1} - \frac{3e}{\sqrt{2}l}Z_{B2} = 0$$

$$+\left[(8+2\sqrt{2})e + (1+\frac{1}{\sqrt{2}})c\right]\phi_{A1} - c\phi_{B1} + 2e\phi_{A2} + \frac{(2e+c)}{2\sqrt{2}}\theta_{B2} + \frac{(2e-c)}{2\sqrt{2}}\phi_{B2} - \frac{3e}{\sqrt{2}l}Z_{B1} = 0$$

$$-\frac{6e}{\sqrt{2}}\theta_{A1} - 6e\theta_{B1} - \frac{3e}{\sqrt{2}}\theta_{B2} - \frac{3e}{\sqrt{2}}\phi_{B2} - 6e\phi_{A2} + \frac{12(3-\frac{1}{\sqrt{2}})e}{l}Z_{A1} + \frac{12e}{l}Z_{B1} + \frac{12e}{l}Z_{A2} + \frac{6e}{\sqrt{2}l}Z_{B2} = 0.$$

In the same way we may obtain the equations for the joints B_1, A_2, B_2.

To illustrate the arrangement of the equations for solution we give the following which apply to the case of the simple braced square $A_0A_1B_1B_0$ with the load W at A_1

Coefficients of						Constants
θ_{A1}	θ_{B1}	ϕ_{A1}	ϕ_{B1}	Z_{A1}	Z_{B1}	
$(1+\frac{1}{2\sqrt{2}})(4e+c)$	$2e$	$\frac{-(4e-c)}{2\sqrt{2}}$	0	$(1+\frac{1}{2\sqrt{2}})\,6e/l$	$-6e/l$	0
$2e$	$(4e+c)$	0	0	$6e/l$	$-6e/l$	0
$\frac{-(4e-c)}{2\sqrt{2}}$	0	$(1+\frac{1}{2\sqrt{2}})(4e+c)$	$-c$	$-(1+\frac{1}{2\sqrt{2}})\,6e/l$	0	0
0	0	$-c$	$(4e+c)$	0	$-6e/l$	0
$(1+\frac{1}{2\sqrt{2}})\,6e/l$	$6e/l$	$-(1+\frac{1}{2\sqrt{2}})\,6e/l$	0	$(1+\frac{1}{4\sqrt{2}})\,24e/l^2$	$-12e/l^2$	W
$-6e/l$	$-6e/l$	0	$-6e/l$	$-12e/l^2$	$24e/l^2$	0

In cases like the above, when the equations involve both angles and deflections, the rate of convergency of the successive approximation process may be slow; in such cases the equations may be dealt with as follows:—

Suppose the equations are

$$F_1(\theta_1, \theta_2, \ldots \theta_n, \phi_1, \phi_2, \ldots \phi_n) + f_1(Z_1, Z_2, \ldots Z_n) = C_1$$
$$F_2(\theta_1, \theta_2, \ldots \theta_n, \phi_1, \phi_2, \ldots \phi_n) + f_2(Z_1, Z_2, \ldots Z_n) = C_2$$

and so on.

The equations may be written

$$f_1(Z_1, Z_2, \ldots Z_n) = A_1$$
$$f_2(Z_1, Z_2, \ldots Z_n) = A_2$$

and so on, where

$$A_r = C_r - F_r(\theta_1, \theta_2, \ldots \theta_n, \phi_1, \phi_2, \ldots \phi_n).$$

The process may be found to be fairly rapidly convergent for the solution of the above equations in the Z's when the A's have any particular values. Thus, when $A_1 = 1$, $A_2 = A_3 = \ldots = A_n = 0$ let the values of the Z's be

$$z_{11}, z_{12}, \ldots z_{1n}.$$

Similarly when $A_1 = 0$, $A_2 = 1$, $A_3 = A_4 = \ldots A_n = 0$, let the values of the Z's be

$$z_{21}, z_{22}, \ldots z_{2n}.$$

Then the vales of the Z's required are

$$Z_1 = z_{11}A_1 + z_{12}A_2 + \ldots + z_{1n}A_n$$
$$Z_2 = z_{21}A_1 + z_{22}A_2 + \ldots + z_{2n}A_n$$

and so on.

We next use these values of Z in the preceding equations of the system and thus obtain $2n$ equations involving the angles only. The process of solution of these equations may also be found to be fairly rapidly convergent. We then obtain the actual values of the angles and consequently the actual values of the deflections.

In the case where the equations are symmetrical about the leading diagonal then it may be shown that

$$z_{21} = z_{12}$$

and so on.

Other means of proceeding may suggest themselves. We may, for instance, put all the θ's and ϕ's zero and find the Z's from the last equations in the Z's. We then use the values of Z so found in the other equations and thus find the corresponding θ's and ϕ's. And so on. By this process, which can be carried out by the tabular method, we eventually arrive at sufficiently approximate values for all the variables.

8. The Space Frame

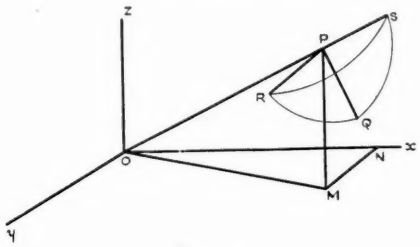


Fig. 7.

Referring to Fig. 7, let λ, μ, ν be the direction angles of the line OP referred to the system of rectangular axes Ox, Oy, Oz.

To find the direction cosines of PQ and PR where PQ is in the plane $zOMP$ and perpendicular to OP, and PR is perpendicular to the plane MOP.

These direction cosines are found to be

$$PR \quad -\cos \mu/\sin \nu, \ \cos \lambda/\sin \nu, \ 0$$
$$PQ \ \cos \lambda \cot \nu, \ \cos \mu \cot \nu, \ -\sin \nu.$$

Let OP now be subjected to three rotations at P as in Fig. 8.

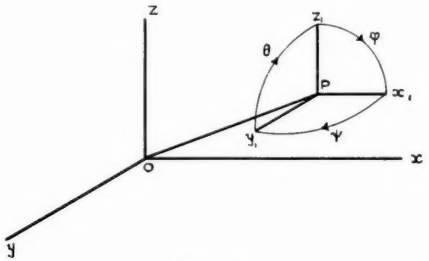


Fig. 8.

These rotations may be resolved as follows:—

(i) About PQ in Fig. 7
$$\theta \cos \lambda \cot \nu + \phi \cos \mu \cot \nu - \psi \sin \nu.$$

(ii) About PR in Fig. 7
$$-\theta \ (\cos \mu/\sin \nu) + \phi \ (\cos \lambda/\sin \nu).$$

(iii) About PS in Fig. 7
$$\theta \cos \lambda + \phi \cos \mu + \psi \cos \nu.$$

Suppose next that OP represents a member of a framework. In its displaced position let

δ_{PQ} be the displacement of the point P relative to O in the plane MOP normal to OP and

δ_{PR} be the displacement of the point P relative to O normal to this plane in the direction PR.

Hence for the fixing moments about PQ and PR we have

$$M_{fPQ} = -(6EI/l^2)\{\delta_{PR}/\phi(a/2)\} \text{ in the direction } SR$$
$$M_{fPR} = -(6EI/l^2)\{\delta_{PQ}/\phi(a/2)\} \text{ in the direction } SQ.$$

Considering the member $(A_1)_o A_1$ we find that

$$(\delta_1)_{PQ} = -\{X_1-(X_1)_o\}\cos\lambda_1\cot\nu_1 - \{Y_1-(Y_1)_o\}\cos\mu_1\cot\nu_1 + \{Z_1-(Z_1)_o\}\sin\nu_1$$
$$(\delta_1)_{PR} = \{X_1-(X_1)_o\}(\cos\mu_1/\sin\nu_1) - \{Y_1-(Y_1)_o\}(\cos\lambda_1/\sin\nu_1)$$

Now

$$M_{PQ} = (M_{f1})_{PQ} + (4E_1I_1/l_1)(\phi a_1/\psi a_1)[\theta_1\cos\lambda_1\cot\nu_1 + \phi_1\cos\mu_1\cot\nu_1 - \psi_1\sin\nu_1] + (2E_1I_1/l_1)(fa_1/\psi a_1)[(\theta_1)_o\cos\lambda_1\cot\nu_1 + (\phi_1)_o\cos\mu_1\cot\nu_1 - (\psi_1)_o\sin\nu_1]$$

$$M_{PR} = (M_{f1})_{PR} + (4E_1I_1/l_1)(\phi a_1/\psi a_1)[-\theta_1(\cos\mu_1/\sin\nu_1) + \phi_1(\cos\lambda_1/\sin\nu_1)] + (2E_1I_1/l_1)(fa_1/\psi a_1)[-(\theta_1)_o(\cos\mu_1/\sin\nu_1) + (\phi_1)_o(\cos\lambda_1/\sin\nu_1)]$$

$$M_{PS} = c_1[\{\theta_1-(\theta_1)_o\}\cos\lambda_1 + \{\phi_1-(\phi_1)_o\}\cos\mu_1 + \{\psi_1-(\psi_1)_o\}\cos\nu_1]$$

Hence

$$\begin{aligned}M_{x1} = (6E_1I_1/l_1^2)(1/\phi\tfrac{1}{2}a_1)[&-\{Y_1-(Y_1)_o\}\cos\nu_1 + \{Z_1-(Z_1)_o\}\cos\mu_1]\\ &+[4e_1(\phi a_1/\psi a_1)\sin^2\lambda_1 + c_1\cos^2\lambda_1]\theta_1\\ &-[4e_1(\phi a_1/\psi a_1) - c_1](\cos\lambda_1\cos\mu_1)\phi_1\\ &-[4e_1(\phi a_1/\psi a_1) - c_1](\cos\lambda_1\cos\nu_1)\psi_1\\ &+[2e_1(fa_1/\psi a_1)\sin^2\lambda_1 - c_1\cos^2\lambda_1](\theta_1)_o\\ &-[2e_1(fa_1/\psi a_1) + c_1](\cos\lambda_1\cos\mu_1)(\phi_1)_o\\ &-[2e_1(fa_1/\psi a_1) + c_1](\cos\lambda_1\cos\nu_1)(\psi_1)_o\end{aligned}$$

$$\begin{aligned}M_{y1} = (6E_1I_1/l_1^2)(1/\phi\tfrac{1}{2}a_1)[&\{X_1-(X_1)_o\}\cos\nu_1 - \{Z_1-(Z_1)_o\}\cos\lambda_1]\\ &-[4e_1(\phi a_1/\psi a_1) - c_1](\cos\lambda_1\cos\mu_1)\theta_1\\ &+[4e_1(\phi a_1/\psi a_1)\sin^2\mu_1 + c_1\cos^2\mu](\phi_1\\ &+[4e_1(\phi a_1/\psi a_1) - c_1](\cos\mu_1\cos\nu_1)\psi_1\\ &-[2e_1(fa_1/\psi a_1) + c_1](\cos\lambda_1\cos\mu_1)(\theta_1)_o\\ &+[2e_1(fa_1/\psi a_1)\sin^2\mu_1 - c_1\cos^2\mu_1](\phi_1)_o\\ &-[2e_1(fa_1/\psi a_1) + c_1](\cos\mu_1\cos\nu_1)(\psi_1)_o\end{aligned}$$

$$\begin{aligned}M_{z1} = (6E_1I_1/l_1^2)(1/\phi\tfrac{1}{2}a_1)[&\{Y_1-(Y_1)_o\}\cos\lambda_1 - \{X_1-(X_1)_o\}\cos\mu_1]\\ &-[4e_1(\phi a_1/\psi a_1) - c_1](\cos\lambda_1\cos\nu_1)\theta_1\\ &-[4e_1(\phi a_1/\psi a_1) - c_1](\cos\mu_1\cos\nu_1)\phi_1\\ &+[4e_1(\phi a_1/\psi a_1)\sin^2\nu_1 + c_1\cos^2\nu_1]\psi_1\\ &-[2e_1(fa_1/\psi a_1) + c_1](\cos\lambda_1\cos\nu_1)(\theta_1)_o\\ &-[2e_1(fa_1/\psi a_1) + c_1](\cos\mu_1\cos\nu_1)(\phi_1)_o\\ &+[2e_1(fa_1/\psi a_1)\sin^2\nu_1 - c_1\cos^2\nu_1](\psi_1)_o\end{aligned}$$

To obtain $(M_{x1})_o$, $(M_{y1})_o$, $(M_{z1})_o$ from the expressions for M_{x1}, M_{y1}, M_{z1}, we write respectively

$2e_1(fa_1/\psi a_1)$ for $4e_1(\phi a_1/\psi a_1)$;
$4e_1(\phi a_1/\psi a_1)$ for $2e_1(fa_1/\psi a_1)$;
and $-c_1$ for c_1.

From conditions of equilibrium at a joint we have

$$\Sigma M_x = 0,\ \Sigma M_y = 0,\ \Sigma M_z = 0,$$

assuming that there are no external moments applied at the joint.

The procedure follows closely that for the plane frame. Thus we first find the linear displacements of the joints on the assumption that these are pin-jointed. From the equations of equilibrium at the joints we then obtain $3j$ simultaneous equations (where j is the number of joints) in the $3j$ angular rotations of the joints. These equations may be solved as in the case of the plane frame.

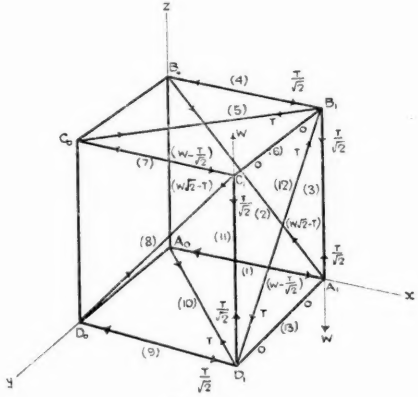


FIG. 9.

As an example of a space frame with rigid joints consider the braced cube illustrated in Fig. 9. The members are all taken to be of the same section and elastic properties. The face $A_0B_0C_0D_0$ is encastered while loads W act at A_1C_1 along the edges B_1A_1, D_1C_1 respectively.

There being one redundancy let T be the load (compression) in the member D_1B_1. The other forces will be as shown in the Fig. We have, therefore, by Castigliano's theorem,

$$E=\tfrac{1}{2}\left[4\left(\frac{T}{\sqrt{2}}\right)^2 x_{11}+2\left(W-\frac{T}{\sqrt{2}}\right)^2 x_{11}+3T^2\sqrt{2}x_{11}+2\,(W\sqrt{2}-T)^2\sqrt{2}x_{11}\right]$$

where x_{11} is the extension (or compression) of all members, except the diagonals, due to unit load along those members.

From the condition $\partial E/\partial T=0$ we find that

$$T=0.54W \text{ app.}$$

Thus

$$\frac{T}{\sqrt{2}}=0.38W,\quad W-\frac{T}{\sqrt{2}}=0.62W \text{ and } W\sqrt{2}-T=0.87W.$$

Let X_{A1}, Y_{A1}, Z_{A1} be the linear displacements of the joint A_1 and similarly for the joints B_1, C_1, D_1. Then assuming that the joints are pin-jointed we find

$$X_{A1}=0.62\,Wx_{11},\quad Y_{A1}=-3.58\,Wx_{11},\quad Z_{A1}=2.36\,Wx_{11}.$$
$$X_{B1}=0.38\,Wx_{11},\quad Y_{B1}=1.46\,Wx_{11},\quad Z_{B1}=1.98\,Wx_{11}.$$
$$X_{C1}=0.62\,Wx_{11},\quad Y_{C1}=1.46\,Wx_{11},\quad Z_{C1}=-2.36\,Wx_{11}.$$
$$X_{D1}=0.38\,Wx_{11},\quad Y_{D1}=-3.58\,Wx_{11},\quad Z_{D1}=-1.98\,Wx_{11}.$$

Taking the members as numbered in the figure we have

Member.	No.	λ	μ	ν
A_0A_1	1	0	90°	90°
B_0A_1	2	45°	90°	135°
B_1A_1	3	90°	90°	180°
B_0B_1	4	0	90°	90°

Member.	No.	λ	μ	ν
C_0B_1	5	45°	135°	90°
C_1B_1	6	90°	180°	90°
C_0C_1	7	0	90°	90°
D_0C_1	8	45°	90°	45°
D_0D_1	9	0	90°	90°
A_0D_1	10	45°	45°	90°
C_1D_1	11	90°	90°	180°
D_1B_1	12	90°	135°	45°
D_1A_1	13	90°	180°	90°

With the foregoing notation and neglecting end load deflection effects, for simplicity, we have

JOINT A_1.

Member.	No.	Components of Moments at A_1.
A_0A_1	1	$M_x = c\theta_{A1}$ $M_y = -(6c/l) \times 2.36\ Wx_{11} + 4c\phi_{A1}$ $M_z = -(6c/l) \times 3.58\ Wx_{11} + 4c\psi_{A1}$
B_0A_1	2	$M_x = (6c/2l) \times 3.58\ Wx_{11} \times 1/\sqrt{2} + (4c+c)\ \theta_{A1}/2\sqrt{2} + (4c-c)\ \psi_{A1}/2\sqrt{2}$ $M_y = -(6c/2l) \times 2.98\ Wx_{11} \times 1/\sqrt{2} + 4c\phi_{A1}/2\sqrt{2}$ $M_z = -(6c/2l) \times 3.58\ Wx_{11} \times 1/\sqrt{2} + (4c-c)\ \theta_{A1}/2\sqrt{2} + (4c+c)\ \psi_{A1}/2\sqrt{2}$
B_1A_1	3	$M_x = -(6c/l) \times 5.04\ Wx_{11} + 4c\theta_{A1} + 2c\theta_{B1}$ $M_y = -(6c/l) \times 0.24\ Wx_{11} + 4c\phi_{A1} + 2c\phi_{B1}$ $M_z = c\ (\psi_{A1} - \psi_{B1})$
D_1A_1	4	$M_x = -(6c/l) \times 4.34\ Wx_{11} + 4c\theta_{A1} + 2c\theta_{D1}$ $M_y = c\ (\phi_{A1} - \phi_{D1})$ $M_z = (6c/l) \times 0.24\ Wx_{11} + 4c\psi_{A1} + 2c\psi_{D1}$

JOINT B_1.

Member.	No.	Components of Moments at B_1.
B_0B_1	4	$M_x = c\theta_{B1}$ $M_y = -(6c/l) \times 1.98\ Wx_{11} + 4c\phi_{B1}$ $M_z = (6c/l) \times 1.46\ Wx_{11} + 4c\psi_{B1}$
C_0B_1	5	$M_x = -(6c/2l) \times 1.98\ Wx_{11} \times 1/\sqrt{2} + (4c+c)\ \theta_{B1}/2\sqrt{2} + (4c-c)\ \phi_{B1}/2\sqrt{2}$ $M_y = -(6c/2l) \times 1.98\ Wx_{11} \times 1/\sqrt{2} + (4c-c)\ \theta_{B1}/2\sqrt{2} + (4c+c)\ \phi_{B1}/2\sqrt{2}$ $M_z = (6c/2l) \times 1.84\ Wx_{11} \times 1/\sqrt{2} + 4c\psi_{B1}/2\sqrt{2}$
C_1B_1	6	$M_x = -(6c/l) \times 4.34\ Wx_{11} + 4c\theta_{B1} + 2c\theta_{C1}$ $M_y = c\ (\phi_{B1} - \phi_{C1})$ $M_z = -(6c/l) \times 0.24\ Wx_{11} + 4c\psi_{B1} + 2c\psi_{C1}$
D_1B_1	12	$M_x = -(6c/2l) \times 8.00\ Wx_{11} \times 1/\sqrt{2} + 4c\theta_{B1}/2\sqrt{2} + 2c\theta_{D1}/2\sqrt{2}$ $M_y = 0 + (4c+c)\ \phi_{B1}/2\sqrt{2} + (4c-c)\ \psi_{B1}/2\sqrt{2} + (2c-c)\ \phi_{D1}/2\sqrt{2} + (2c+c)\ \psi_{D1}/2\sqrt{2}$ $M_z = 0 + (4c-c)\ \phi_{B1}/2\sqrt{2} + (4c+c)\ \psi_{B1}/2\sqrt{2} + (2c+c)\ \phi_{D1}/2\sqrt{2} + (2c-c)\ \psi_{D1}/2\sqrt{2}$
B_1A_1	3	$M_x = -(6c/l) \times 5.04\ Wx_{11} + 4c\theta_{B1} + 2c\theta_{A1}$ $M_y = -(6c/l) \times 0.24\ Wx_{11} + 4c\phi_{B1} + 2c\phi_{A1}$ $M_z = c\ (\psi_{B1} - \psi_{A1})$

θ_{A1}	θ_{B1}	θ_{C1}	θ_{D1}	ϕ_{A1}	ϕ_{B}
$(8+\sqrt{2})\,e+(1+1/2\sqrt{2})\,c$	$2e$	0	$2e$	0	0
$2e$	$(8+2\sqrt{2})\,e+(1+1/2\sqrt{2})\,c$	$2e$	$e/\sqrt{2}$	0	$(4\,e-c$
0	$2e$	$(8+\sqrt{2})\,e+(1+1/2\sqrt{2})\,e$	$2e$	0	0
$2e$	$e/\sqrt{2}$	$2e$	$(8+2\sqrt{2})\,e+(1+1/2\sqrt{2})\,e$	0	0
0	0	0	0	$(8+\sqrt{2})\,e+e$	$2e$
0	$(4\,e-e)/2\sqrt{2}$	0	0	$2e$	$(8+2\sqrt{2})\,e+$
0	0	0	0	0	—
0	0	0	$-(4\,e-e)/2\sqrt{2}$	$-e$	$(2\,e-e)$
$(4\,e-e)\,2\sqrt{2}$	0	0	0	0	0
0	0	0	0	0	$(4\,e-e)$
0	0	$-(4\,e-e)/2\sqrt{2}$	0	0	0
0	0	0	0	0	$(2\,e+e)$

TABLE IV.

Coefficients of

	ϕ_{B1}	ϕ_{C1}	ϕ_{D1}	ψ_{A1}	ψ_{B1}
	0	0	0	$(4c-c)/2\sqrt{2}$	0
	$(4c-c)/2\sqrt{2}$	0	0	0	0
	0	0	0	0	0
	0	0	$-(4c-c)/2\sqrt{2}$	0	0
$)c+c$	$2c$	0	$-c$	0	0
	$(8+2\sqrt{2})c+(1+1/\sqrt{2})c$	$-c$	$(2c-c)/2\sqrt{2}$	0	$(4c-c)/2\sqrt{2}$
	$-c$	$(8+\sqrt{2})c+c$	$2c$	0	0
	$(2c-c)/2\sqrt{2}$	$2c$	$(8+2\sqrt{2})c+(1+1/\sqrt{2})c$	0	$(2c+c)/2\sqrt{2}$
	0	0	0	$(8+\sqrt{2})c+(1+1/2\sqrt{2})c$	$-c$
	$(4c-c)/2\sqrt{2}$	0	$(2c+c)/2\sqrt{2}$	$-c$	$(8+2\sqrt{2})c+(1+1/2\sqrt{}$
	0	0	0	0	$2c$ $(8+$
	$(2c+c)/2\sqrt{2}$	0	$(4c-c)/2\sqrt{2}$	$2c$	$(2c-c)/2\sqrt{2}$

ψ_{B1}	ψ_{C1}	ψ_{D1}	Constants
0	0	0	48.69 (Wk^2/l)
0	0	0	77.44 (Wk^2/l)
0	$-(4e-c)/2\sqrt{2}$	0	59.38 (Wk^2/l)
0	0	0	77.44 (Wk^2/l)
0	0	0	21.92 (Wk^2/l)
$-c)/2\sqrt{2}$	0	$(2e+c)/2\sqrt{2}$	17.52 (Wk^2/l)
0	0	0	-21.92 (Wk^2/l)
$+c)/2\sqrt{2}$	0	$(4e-c)/2\sqrt{2}$	-17.52 (Wk^2/l)
$-c$	0	$2e$	31.51 (Wk^2/l)
$+(1+1/2\sqrt{2})c$	$2e$	$(2e-c)/2\sqrt{2}$	-11.22 (Wk^2/l)
$2e$	$(8+\sqrt{2})e+(1+1/2\sqrt{2})c$	$-c$	10.42 (Wk^2/l)
$-c)/2\sqrt{2}$	$-c$	$(8+2\sqrt{2})e+(1+1/2\sqrt{2})c$	27.24 (Wk^2/l)

JOINT C_1.

Member.	No.	Components of Moments at C_1.
C_1B_1	6	$M_x = -(6e/l) \times 4.34\ Wx_{11} + 4e\theta_{C1} + 2e\theta_{B1}$ $M_y = e\ (\phi_{C1} - \phi_{B1})$ $M_z = -(6e/l) \times 0.24\ Wx_{11} + 4e\psi_{C1} + 2e\psi_{B1}$
C_0C_1	7	$M_x = e\theta_{C1}$ $M_y = (6e/l) \times 2.36\ Wx_{11} + 4e\phi_{C1}$ $M_z = (6e/l) \times 1.46\ Wx_{11} + 4e\psi_{C1}$
D_0C_1	8	$M_x = -(6e/2l) \times 1.46\ Wx_{11} \times 1/\sqrt{2} + (4e+e)\ \theta_{C1}/2\sqrt{2} - (4e-e)\ \psi_{C1}/2\sqrt{2}$ $M_y = (6e/2l) \times 2.98\ Wx_{11} \times 1/\sqrt{2} + 4e\phi_{C1}/2\sqrt{2}$ $M_z = (6e/2l) \times 1.46\ Wx_{11} \times 1/\sqrt{2} - (4e-e)\ \theta_{C1}/2\sqrt{2} + (4e+e)\ \psi_{C1}/2\sqrt{2}$
C_1D_1	11	$M_x = -6e/l \times 5.04\ Wx_{11} + 4e\theta_{C1} + 2e\theta_{D1}$ $M_y = 6e/l \times 0.24\ Wx_{11} + 4e\phi_{C1} + 2e\phi_{D1}$ $M_z = e\ (\psi_{C1} - \psi_{D1})$

JOINT D_1.

Member.	No.	Components of Moments at D_1.
D_0D_1	9	$M_x = e\theta_{D1}$ $M_y = (6e/l) \times 1.98\ Wx_{11} + 4e\phi_{D1}$ $M_z = -(6e/l) \times 3.58\ Wx_{11} + 4e\psi_{D1}$
A_0D_1	10	$M_x = -(6e/2l) \times 1.98\ Wx_{11} \times 1/\sqrt{2} + (4e+e)\ \theta_{D1}/2\sqrt{2} - (4e-e)\ \phi_{D1}/2\sqrt{2}$ $M_y = (6e/2l) \times 1.98\ Wx_{11} \times 1/\sqrt{2} - (4e-e)\ \theta_{D1}/2\sqrt{2} + (4e+e)\ \phi_{D1}/2\sqrt{2}$ $M_z = -(6e/2l) \times 3.98\ Wx_{11} \times 1/\sqrt{2} + 4e\psi_{D1}/2\sqrt{2}$
C_1D_1	11	$M_x = -(6e/l) \times 5.04\ Wx_{11} + 4e\theta_{D1} + 2e\theta_{C1}$ $M_y = (6e/l) \times 0.24\ Wx_{11} + 4e\phi_{D1} + 2e\phi_{C1}$ $M_z = e\ (\psi_{D1} - \psi_{C1})$
D_1B_1	12	$M_x = -(6e/2l) \times 8.00\ Wx_{11} \times 1/\sqrt{2} + 4e\theta_{D1}/2\sqrt{2} + 2e\theta_{B1}/2\sqrt{2}$ $M_y = 0 + (4e+e)\ \phi_{D1}/2\sqrt{2} + (4e-e)\ \psi_{D1}/2\sqrt{2} + (2e-e)\ \phi_{B1}/2\sqrt{2}$ $\quad + (2e+e)\ \psi_{B1}/2\sqrt{2}$ $M_z = 0 + (4e-e)\ \phi_{D1}/2\sqrt{2} + (4e+e)\ \psi_{D1}/2\sqrt{2} + (2e+e)\ \phi_{B1}/2\sqrt{2}$ $\quad + (2e-e)\ \psi_{B1}/2\sqrt{2}$
D_1A_1	13	$M_x = -(6e/l) \times 4.34\ Wx_{11} + 4e\theta_{D1} + 2e\theta_{A1}$ $M_y = e\ (\phi_{D1} - \phi_{A1})$ $M_z = (6e/l) \times 0.24\ Wx_{11} + 4e\psi_{D1} + 2e\psi_{A1}$

By considering the equilibrium of the moments at the joints we obtain the twelve simultaneous equations given in Table IV. These equations may be readily solved for particular numerical values by the methods previously used.

Assuming that $e = 0.8\,e$ we find that the values of the twelve angles are in radians

$$\theta_{A1} = 2.43\ w,\ \theta_{B1} = 5.14\ w,\ \theta_{C1} = 3.65\ w,\ \theta_{D1} = 5.12\ w;$$
$$\phi_{A1} = 2.01\ w,\ \phi_{B1} = 0.47\ w,\ \phi_{C1} = -1.99\ w,\ \phi_{D1} = -0.64\ w;$$
$$\psi_{A1} = 2.33\ w,\ \psi_{B1} = -0.82\ w,\ \psi_{C1} = -0.34\ w,\ \psi_{D1} = 1.91\ w;$$
$$\text{where } w = W/EA$$

and A is the area of cross section.

From these values together with the other data available the loading actions in all the members may readily be found.

In the case of a more elaborate braced space frame, the number of variables involved in the simultaneous equations ($3 \times$ number of joints) may render solution tedious. In such a case an approximation may be obtained as follows:—

First find the linear displacements of the joints on the assumption that the latter are pin-jointed. Then find the appropriate simultaneous equations for one or two bays assuming that there are no rotations of the joints at the far ends of the members of these one or two bays as the case may be. Solve these equations and thus find the loading actions in these one or two bays and the consequent reaction at the joints held fixed. Next release these joints and find the loading action in the next one or two bays as the result of the reactions already found, and so on. This, of course, will not give the true values of the loading actions, but may give sufficiently close approximations to them.

ABSTRACTS AND NOTICES
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LIST OF ABBREVIATIONS OF TITLES OF JOURNALS.

Aer. Res. Inst. Tokio	Aeronautical Research Institute of Tokio.
Aeron. Eng.	Aeronautical Engineering.
A.C.I.C.	Air Corps Information Circular.
Airc. Eng.	Aircraft Engineering.
Ann. d. Phys.	Annalen der Physik.
Army Ord.	Army Ordinance.
Autom. Absts.	Automotive Abstracts.
Autom. Tech. Zeit.	Automobiltechnische Zeitschrift.
Autom. Eng.	Automobile Engineer.
Autom. Ind.	Automotive Industries.
Bell Tele. Pubs.	Bell Telephone Publications.
Bur. Stan. J. Res.	Bureau of Standards (U.S.A.) Journal of Research.
Comp. Rend.	Comptes Rendus de l'Academie des Sciences.
Chem. Absts.	Chemical Abstracts.
Chem. and Ind.	Chemistry and Industry.
D.M.Z.	Deutsche Motor-Zeitschrift
Eng. Absts.	Engineering Abstracts.
Forschung	Forschung auf dem Gebiete des Ingenieurwesins.
Fuel.	Fuel in Science and Practice.
H.F. Technik.	Hochfrequenztechnik und Electroa Kustik.
Ind. and Eng. Chem.	Industrial and Engineering Chemistry.
Inst. Autom. Eng.	Institution of Automobile Engineers. Research and Standardisation Committee.
J. Aer. Sci.	Journal of the Aeronautical Sciences.
J. App. Mech.	Journal of Applied Mechanics.
J.R. Aer. Soc.	Journal of Royal Aeronautical Society.
J. Frank. Inst.	Journal of Franklin Institute.
J. Sci. Inst.	Journal of Scientific Instruments.
J. Am. Soc. Nav. Eng.	Journal of American Society of Naval Engineers.
J. Inst. Elec. Eng.	Journal of Institute of Electrical Engineers.
J. Inst. Civ. Eng.	Journal of the Institution of Civil Engineers.
J. Met. Soc.	Journal of the Meteorological Society.

J.S.A.E.	Journal of Society of Automotive Engineers.
L'Aéron.	L'Aéronautique.
L.F.F.	Luftfahrtforschung.
Met. Mag.	Meteorological Magazine.
Met. Prog.	Metal Progress.
N.A.C.A.	National Advisory Committee for Aeronautics (U.S.A.)
Proc. Camb. Phil. Soc.	Proceedings of Cambridge Philosophical Society.
Phil. Mag.	Philosophical Magazine.
Phys. Berichte	Physikalische Berichte.
Phys. Zeit.	Physikalische Zeitschrift.
Proc. Inst. Rad. Eng.	Proceedings of the Institute of Radio Engineers.
Phil. Trans. Roy. Soc.	Philosophical Transactions of the Royal Society.
Proc. Roy. Soc.	Proceedings of Royal Society.
Pub. Sc. et Tech.	Publications Scientifiques et Techniques du Ministère de l'Air.
R. & M.	Reports and Memoranda of the Aeronautical Research Committee.
Riv. Aeron.	Rivista Aeronautica.
Rev. de l'Arm. de l'Air	Revue de l'Armée de l'Air.
Sci. Am.	Scientific American.
Sci. Absts. (A or B)	Science Abstracts (A or B).
Tech. Aéron.	La Technique Aéronautique.
Trans. A.S.M.E.	Transactions of the American Society of Mechanical Engineers.
W.R.H.	Werft-Reederei-Hafen.
Z.A.M.M.	Zeitschrift für Angewandte Mathematik und Mechanik
Z.F.M.	Zeitschrift für Flugtechnik und Motorluftschiffahrt.
Z.G.S.S.	Zeitschrift für Das Gesamte Schiess und Sprenstoffwesen.
Z. Instrum.	Zeitschrift für Instrumentenkunde.
Z. Metallk.	Zeitschrift für Metallkunde.
Z.V.D.I.	Zeitschrift für Vereines Deutscher Ingenieure.
Z. Mech.	Zentralblatt für Mechanik.

PART I.

PHYSICS AND ENGINEERING SCIENCE.

Acoustics

On the Propagation of Supersonic Sound Waves in Liquids. (R. Lucas, Comptes Rendus, Vol. 201, No. 24, 9/12/35, pp. 1172-1174.) (544 France.)

Experiments have shown that the reduction in intensity of supersonic sounds is greater than can be accounted for by transformation of sound energy into heat absorption coefficients given by Stoke and Kirchhoff.

The author suggests that the waves are scattered by molecular aggregate. The effect may be increased if there are variations in density throughout the liquid.

Investigations on the Origin of the Sound Emitted by Revolving Airscrews. (J. Obata and others, Aer. Res. Inst. Tokio, No. 132, Dec., 1935.) (753 Japan.)

The sound of a rotating airscrew consists of three parts:—

(1) Sound due to pressure differences on the two sides of the blade.
(2) Sound due to vortices.
(3) Sound due to elastic vibration of the blade.

The present paper deals with (1).

The model airscrew (metal, approx. 1 m. diameter) was rotated in the open at 2,500 r.p.m. and the pressure variations in the air at different distances from the blade was investigated by means of a condenser microphone. It appears that the velocity of propagation of the suction impulse in front of the blade exceeds the velocity of sound.

In a future paper the authors propose to deal with the directional properties of the sound emitted.

The Production and Measurement of Slow Pressure Vibrations of Sine Form in Air. (G. Bekesy, Annalen der Physik, Vol. 25, No. 5, pp. 413-432.) (764 Germany.)

It appears probable that the perception and analysis of low frequency sounds is no longer governed by the dimension of the cochlea, but take place directly in the auditory nerve. The author describes several methods of producing pure sine pressure variations, some mechanical and others electrical, producing sound pressure of the order of 20 gm./cm.^{2} in the auditory canal.

A subsequent article will deal with physiological effects.

The Frequency Spectrum and the Perception of a Note. (W. Burk, P. Kobowski and H. Lichte, Annalen der Physik, Vol. 25, No. 5, pp. 433-499.) (765 Germany.)

In order to perceive a definite note when the background is a continuous sound spectrum, it is necessary that 70 per cent. of the total radiated energy should be concentrated in a frequency belt of ± 5 per cent.

Vibrations of Air and CO_2 in Closed Spherical Resonators. (K. Voekler, Annalen der Physik, Vol. 24, Part 4, Oct., 1935, pp. 361-376.) (206 Germany.)

Vibrations were initiated by an electrically operated telephone membrane forming part of the surface of the sphere. The air vibrations were recorded optically by the motion of a thin (1/200 m/m. thickness) diaphragm of mica or tin foil.

Metal resonators introduced complications by their own vibrations. This difficulty was overcome by using spheres of plaster of paris.

Frequency measurement were in good agreement with theory (Rayleigh and Thiessen) as regards frequency, but only qualitative for damping of vibrations.

The damping depends very much on the order of the vibration and is also affected by moisture. CO_2 gives less damping than air.

Aerodynamics and Hydrodynamics

Turbulent Friction Layers in Curved Flow. (E. Gruschwitz, Ing. Archiv., Vol. 6, Part 5 (Oct.), 1935, pp. 355-365.) (203 Germany.)

Following a suggestion of Prof. Prandtl, the author introduces the term " friction layer " for what has so far been termed " boundary layer."

This latter term is retained for the laminar part of the friction layer.

Measurements are described of the flow along a flat wall, the potential flow line being curved in plane parallel to the wall.

The usual equations for the turbulent layer in plane flow as observed by the impulse method (Kármán) are extended to this case of three dimensioned flow and the shear stresses along the wall are calculated.

Comparison of this shear stress with that of plane flow shows no systematic difference.

NOTE.—See also " Turbulent layer of friction in two-dimensional flow with pressure drop and increase," by E. Gruschwitz (Translation No. 67A, List No. 1).

The Interdependence of Profile Drag and Lift with Joukowski Type and Related Airfoils. (H. Muttray, N.A.C.A. Tech. Memo., No. 768, 1935.) (267 U.S.A.)

Up to camber parameters $f/l=0.25$ and thickness parameters $d/l=0.4$, the profile drag coefficient is represented by a cubical parabola whose apex for cambered profile lies above the axis of resistance coefficients.

A Method of Showing up Small Differences in Density in Fluids, and its Application, to Study the Movement of Fluid in the Neighbourhood of a Swimming Fish. (A. and C. Magnan, Comptes Rendus, Vol. 201, No. 21, 18/11/35, pp. 937-938.) (479 France.)

The liquid is placed in front of a concave mirror of large aperture and illuminated by means of a point source. The reflected image is photographed in a high-speed cine camera.

Differences in density in the liquid are produced by immersing a hot wire. The fish employed was of a small tropical species and the photographs show the displacement of the warm liquid current by the fins. Whilst the vertical fins project the water mainly downward, the tail fin produces a powerful displacement to the rear.

Turbulent Flow in a Circular Pipe. (A. Fage, Phil. Mag., Vol. 21, No. 138, Jan., 1936, pp. 80-105.) (497 Great Britain.)

Distribution of the mean velocity (U), the maximum longitudinal velocity fluctuation (u_1) and of the maximum angular deviations from the axial direction of the path of particles moving in axial and tangential planes were measured with the aid of the ultramicroscope.

Maximum values of the radial and tangential components (v_1 and w_1) were deduced.

The distribution of turbulent components bear a general resemblance to those obtained previously with a round pipe, the ratios u_1/v_1 and v_1/w_1 are however greater.

Contribution to the Study of the Propulsion of Fishes. (A. Magnan and C. Magnan, Comptes Rendus, Vol. 201, No. 26, 23/12/35, pp. 1429-1430.) (548 France.)

For short distances the small tropical " Platis " fish previously experimented on (see Abstract No. 8) attained a forward speed of 56 cm./sec. by the reaction of 2.8 gm./sec. of water propelled at 24 cm./sec. This corresponds to approximately 1/100 h.p. per 100 kg. of animal weight.

In their experiments with insects and birds (see Abstract No. 30,829) the authors obtained values of the order of 3.5 h.p. and 4 h.p. per 100 kg. of animal weight respectively.

An Application of the Von Kármán-Milikan Laminar Boundary Layer Theory and Comparison with Experiment. (A. E. Von Doenhoff, N.A.C.A. Tech. Note No. 544, Oct., 1935.) (631 U.S.A.)

The computed and experimental characteristics of the laminar boundary layer about the elliptic cylinder are in good agreement. This agreement indicates that the method may be generally applied to the laminary boundary layer about any type of body provided that an experimentally determined pressure distribution is available. It appears that for all Reynolds numbers above 24,000 the separation point for the elliptic cylinder should occur at a constant distance behind the point of minimum pressure, provided that the boundary layer does not become turbulent.

The Compressibility Burble. (J. Stack, N.A.C.A. Tech. Note No. 543, Oct., 1935.) (632 U.S.A.)

Model experiments on an aeroplane wing show a rapid increase in minimum profile drag (from 0.015 to 0.10) as the velocity of the air (at some distance from the wing) increases from 0.7 to 0.85 that of the velocity of sound. Schlieren photographs demonstrate that the rapid increase is due to compression shock, the air speed reaching supersonic velocities in the neighbourhood of the upper surface of the wing.

The Theory of the Laminary Boundary Layer in Compressible Gases. (F. Frankl, Report of Central Aero-Hydrodynamical Inst., Moscow, No. 176, 1934, pp. 3-18.) (658 Russia.)

The present work contains a generalised theory of the boundary layer of compressible gases undergoing laminar flow.

The method used is an extension of that of Kármán-Pohlhausen, and the conclusion is reached that for a flat plate the effect of compressibility is to reduce the resistance coefficient as the speed increases. The conditions necessary for stable laminar motion have also been investigated and are in agreement with experiment.

The Growth of Prandtl's Boundary Layer in Rectangular Tubes for a Laminar Flow Condition. (Frankl and Balanov, Report of Central Aero-Hydrodynamical Inst., Moscow, No. 176, 1934, pp. 19-32.) (659 Russia.)

The following assumptions are made:—

(*a*) That the core of the flow is a rectangle of similar shape to the tube, the boundary layer filling the outside frame.

(*b*) That at the end of the so-called " starting distance " the velocity distribution in the outer frame follows Poiseuille's Law.

Length of starting distance pressure drop and growth of boundary layer are investigated for rectangular side ratios of 1/1 and 1/2.

On the Heat Generated in a Body Placed in a High-Speed Air Current. (E. Brun and R. Lecardonnel, Comptes Rendus, Vol. 202, No. 7, 17/2/36, pp. 555-556.) (806 France.)

Experiments were carried out in an air stream approximately 30 cm. in diameter. The net rise in temperature $d\theta$°C. of a thermocouple due to air friction was given by the relation $d\theta = 4.2 \times 10^{-4} v^2$ for speeds up to 200 m./sec.

Application of Bessel Functions to the Solution of Problem of Motion of a Circular Disc in Viscous Liquid. (M. Ray, Phil. Mag., Vol. 21, No. 141, March, 1936, pp. 546-564.) (863 Great Britain.)

Previous solutions of the problem were based on the gravitational potential function of the ellipsoid, the fluid moving in circles perpendicular to the axis.

The problem of the rotating disc is deduced as a limiting case.

The author presents a direct solution of the disc problem in terms of Bessel functions.

Note on the Development of the Circulation Around a Thin Elliptic Cylinder. (L. Howarth, Proc. Camb. Phil. Soc., Vol. 31, Part 4, 1935, pp. 582-584.) (905 Great Britain.)

In a previous paper (see Abstract No. 30,668), the present writer gave a solution of the problem of determining the circulation around a thin elliptic cylinder in a steady stream of slightly viscous fluid when the major axis of the cylinder is inclined at a small angle to the direction of the flow at infinity. The present

note gives a largely qualitative analysis of the manner in which this circulation is built up when the motion of the fluid or cylinder is started instantaneously from rest with a given velocity.

Note on the Flow Past a Circular Cylinder. (L. Howarth, Proc. Camb. Phil. Soc., Vol. 31, Part 4, 1935, pp. 585-588.) (906 Great Britain.)

Buri's method of solution of the equation of turbulent motion in a boundary layer has been used in a previous paper (see Abstract No. 30,668).

The method has now been applied to the case of a circular cylinder for which experimental data are available for comparison.

The comparisons do not fully substantiate the method, but the predictions are sufficiently near not to condemn the method.

The method should be checked by further experiments.

The Gliding of a Plate on a Stream of Finite Depth. (A. E. Green, Proc. Camb. Phil. Soc., Vol. 31, Part 4, 1935, pp. 589-603.) (907 Great Britain.)

The two-dimensional problem of an inclined plane, infinite in one direction, gliding on the surface of water of infinite depth, has been solved by Wagner and applied to the discussion of the dynamics of seaplanes (see Translation No. 247, List No. 1). In Wagner's work the trailing edge of the plane was necessarily at an infinite height above the undisturbed surface of the water, and so does not represent the conditions obtained in practice. Thus it is interesting to examine the case of gliding on a stream of finite depth.

The case considered is that of the two-dimensional gliding of a semi-infinite plate and expressions are obtained for the lift L in terms of the ratio D/H when H is the depth at infinity up stream and D is the height of the trailing edge of the plate above the surface of the stream.

It is concluded that the trailing edge cannot be at more than a height of 0.07 H above the upstream fluid surface.

For list of references see H. Wagner, Proc. 4th Inter. Congress for Applied Mechanics, Cambridge (1934), p. 146 (Translation No. 247, List No. 1).

Resistance of a Sphere Rotating about an Axis Parallel to the Wind. (S. Luthander and A. Rydberg, Phys. Zeit., Vol. 36, No. 16, 15/8/35, pp. 552-558.) (908 Germany.)

The experiments were carried out at the Royal Technical High School, Stockholm. A hollow copper sphere of 20 cm. diameter was polished, mounted as an axle running in ball bearings and balanced.

The axle bearings were suspended by wires downstream from the sphere so as to avoid disturbance. Wind velocities up to 24 metres per second and rotations up to 3,800 per minute were imposed.

The resistance of the sphere at rest is compared graphically with the Göttingen figures and shows systematically smaller values for the whole range of Reynolds number.

The resistance of the sphere in rotation is shown graphically for 12 different angular velocities as a function of Reynolds number. The curves show the well-known discontinuity for low angular velocities, but at high angular velocities the curves run smoothly within the range of Reynolds numbers shown.

The results are also plotted for different ratios of angular to axial velocity.

Six smoke photographs show the general appearance of the wake and the apparent potential flow outside the wake. At high axial velocity the wake shows a Vena Contracta and resembles the wake of an airscrew in outline.

The position of the point of diversion of the surface streamline was observed for a large variety of conditions, and the results are exhibited graphically.

It was found possible to account for the experimental results in a qualitative manner, using the known critical Reynolds number for a flat plate.

(Translation No. 124, List No. 1.)

Aircraft—Design and Performance

The First International Italian Aero Exhibition. (L'Aerophile, Vol. 43, No. 11, Nov., 1935, pp. 323-324.) (332 France.)

The exhibits enable the following conclusions to be drawn :—

1. Extensive use of steel and light alloys both for frame and wing covering.
2. General employment of flaps.
3. Improved comfort for passengers (ventilating, heating, cooling, noise).
4. Cantilever construction and retractable undercarriage becoming more general.

Summaries of Papers on the Problem of High-Speed Flying Presented at the Volta Conference, Rome, October, 1935. (L'Aerotecnica, Vol. 15, No. 9-10, Sept.-Oct., 1935, pp. 861-914.) (333 Italy.)

1. Technical development work in England in connection with the Schneider Competition, 1931. (H. E. Wimperis.)
2. Italian high-speed machines. (M. Castoldi.)
3. Italian engine for high-speed aeroplane. (C. F. Bona.)
4. High-speed flying and breathing of pilots (British experiments). (C. F. Stainforth.)
5. High-speed flying and breathing of pilot (Italian experiments). (M. Bernasconi.)
6. General consideration about the flow of a compressible fluid. (L. Prandtl.)
7. Stability of flow at high speeds. (G. I. Taylor.)
8. The effect of compressibility on fluid resistance. (T. de Karman.)
9. Lift at high speeds (below that of sound). (E. Pistolesi.)
10. Aerodynamic lift at supersonic speeds (in course of translation). (A. Buseman.)
11. Experimental technique at high speeds. (M. Panetti.)
12. American experimental researches on high-speed aerodynamic phenomena. (E. N. Jacobs.)
13. Experiments with model propellers. (G. P. Douglas.)
14. High-speed wind tunnels. (J. Ackeret.)
15. Thermodynamics of high altitude engines. (H. R. Ricardo.)
16. High altitude engines. Mechanism and cooling. (A. Anastasi.)
17. Stratosphere flight (translation No. Y.53). (G. Costanzi.)
18. Jet propulsion (in course of translation). (M. Roy.)
19. Rocket propulsion. (N. A. Rinin.)

Flexional Valuation of Cantilever Wings. A Case of Integrability. (C. Vairano, L'Aerotecnica, Vol. 15, No. 9-10, Sept.-Oct., 1935, pp. 938-943.) (335 Italy.)

The equation of transverse vibrations of a wing (considered as a clamped beam) is developed, taking into account internal damping and air resistance. A separation of variables is rendered possible on the supposition that the ratio of mass loading to the resistance coefficient is constant along the wing.

If mass and moment of inertia vary along the wing exponentially an elementary solution is possible.

The Drag of Airplane Wheels, Wheel Fairings, and Landing Gears—III. (W. H. Herrnstein and D. Biermann, N.A.C.A. Report No. 522, 1935.) (343 U.S.A.)

The drag of a conventional tripod landing gear with streamline wheels can be reduced about 39 per cent. by careful fairing of all strut intersections.

The drags of tail-wheel units and tail-skids are, even in the worst case, almost negligible.

Investigation of Full-Scale Split Trailing-Edge Wing Flaps with Various Chords and Hinge Locations. (R. Wallace, N.A.C.A. Report No. 539, 1935.) (344 U.S.A.)

Split trailing edge flaps materially affected the magnitude and distribution of pressures over the entire wing profile. At low angles of attack the predominant effect of the flaps was to increase positively the lower surface pressures; at high angles of attack to increase negatively the upper surface pressures. Down wash surveys indicated that horizontal tail planes located above the wing chord line would be more effective than those below the chord in counteracting the increased diving moment of the airplane with flaps deflected.

A Flight Investigation of the Spinning of the F4B-2 Biplane with Various Loads and Tail Surfaces. (N. F. Scudder and O. Seidman, N.A.C.A. Report No. 529, 1935.) (415 U.S.A.)

A flight investigation of the spinning of the F4B-2 single-seater fighter airplane was made for the purpose of finding modifications that would eliminate dangerous spin tendencies exhibited by this type of airplane in service.

Raising the horizontal surfaces gave the most pronounced beneficial effect on recovery, making possible recoveries in less than one turn. The alterations made to the horizontal and vertical surfaces for the tests did not introduce undesirable flying characteristics. Flight tests and model tests were in general agreement, but there were apparent discrepancies in certain details, particularly in regard to the comparative merits of several ways of manipulating the controls for recovery.

Study of Air Flow Round a Wing—Effect of Wing Tips. (J. Valensi, Comptes Rendus, Vol. 201, No. 21, 18/11/35, pp. 940-942.) (480 France.)

The author has developed a method of taking smoke pictures on a cine camera, the model wing being in a wind channel. The top vortices are clearly shown, the vortex core being well above the wake of the wing and visible for a considerable distance.

Stalling of Tapered Wings. (G. V. Lachmann, Flight, Vol. 29, No. 1410, 2/1/36, pp. 10-13.) (507 Great Britain.)

A rectangular wing stalls first at the centre portion, whilst tapered wings will stall near the wing tips.

Tip stalling can be controlled by twisting the wing so that the tips are at a smaller (geometrical) angle of incidence. This procedure, however, increases the drag considerably.

The writer recommends the fitting of a slotted flap to the central portion of the tapered wing and a tip slot to the outer portion. It is claimed that the tip slots contribute very materially to the maximum lift obtainable, even at the stalling angle of the ordinary section, whereas on a rectangular wing the contribution to total lift at normal stalling angles is negligible.

The Determination of Air Pressure on the Wings of a Pigeon in Flight. (A. Magnan and H. Girerd, Comptes Rendus, Vol. 201, No. 24, 9/12/35, pp. 1221-1223.) (546 France.)

The experimental apparatus has been described in Comptes Rendus, Vol. 201, 1935, p. 1145. Pressure curves on a time basis are reproduced, showing variation of air pressure at a point on the upper and another point on the lower wing surface whilst the bird

(*a*) Ran along the ground prior to take off;
(*b*) Was in horizontal flight;
(*c*) Hovering;
(*d*) Landing.

In horizontal flight, the suction on the top of the wing, although variable persists during the whole motion of the wing. The suction on the bottom surface of the wing is negligible.

So far pressure plotting has only been carried out over a few points of the wing surface, but the experiments, as far as they go, render it difficult to believe that the values obtainable will be sufficient to account for the observed lift.

Vibration Characteristics of Twenty Air Corps Airplanes. (A.C.I.C., Vol. 8, No. 702, 1/9/35, p. 3.) (572 U.S.A.)

The airplane structure is always susceptible to resonant vibration from the exciting forces generated by the rotating engine parts and cylinder explosion impulses.

The prevention or elimination of the buffeting type of surface vibration requires the use of properly shaped wing fuselage fillets.

The prevention of flutter requires the use of dynamically balanced surfaces. The degree of dynamic balance depends upon the relative value of the interacting natural frequencies. As yet there are not sufficient data available to determine the exact amount of dynamic balance for various combinations of the flutter matching frequencies.

The prevention of resonant structural vibration produced by the exciting forces generated in the engine requires a properly designed vibration isolating engine mount. Six references.

Airscrew Engine Combinations and their Effect on the Take-off. (G. V. Lachmann, Aircraft Engineer (Supplement to Flight), Nos. 1392 and 1396, August 29th, 1935, pp. 7-9, and Sept. 26th, 1935, pp. 15-19.) (585 Great Britain.)

Two kinds of aircraft are considered, the conventional service type (termed "slow") and a type of the future ("fast"). The various means for improving "take-off" are discussed. Briefly, these are:—

(*a*) High ground boost, 8lbs./sq. in.
(*b*) Low ground boost, 2lbs./sq. in.
(*c*) Two speed blower.
(*d*) Variable pitch airscrew.

The combinations recommended are as follows:—

Slow Aircraft.—High boost and fixed pitch airscrew.

Fast Aircraft.—High boost and variable pitch airscrew.

This presupposes engine design capable of withstanding high boost over moderate periods.

Static Propeller Thrust and Model Experiments. (C. N. H. Lock and H. Bateman, Aircraft Engineer (Supplement to Flight), No. 1401, 3/10/35, p. 2F.) (586 Great Britain.)

A comparison between N.P.L. model experiments (R. & M. 829) and American full-scale experiments (F. W. Caldwell, S.A.E. Journal, August and September, 1934), reveals discrepancies which were considered by Lachmann (see Abstract No. 585) to be due to wall interference.

The authors point out that the difference is mainly due to differences in blade section of the model and full-scale, which difference becomes especially important when operating in the region of the stall.

Stalling of Tapered Wings. (W. R. Andrews, Flight, Vol. 29, No. 1413, 23/1/36, pp. 1-3 of Suppt., The Aircraft Engineer.) (655 Great Britain.)

The general applicability of the conclusions of Lachmann (see Abstract No. 507) as to the stalling of tapered wings are questioned, since they apply only to wings of constant thickness ratio along the span or to a wing having a reflexed trailing edge. For a more usual wing arrangement where the tip chord is about half the roof chord, and when body and engine interferences have to be taken into account, it is not anticipated that initial stall will take place at or near the tips, but rather in the centre as in a straight wing.

There is thus no need for a wing tip slot.

Limitations of the Pilot in Applying Forces to Airplane Controls. (M. N. Gough and A. P. Beard, N.A.C.A. Tech. Note No. 550, Jan., 1936.) (750 U.S.A.)

A cockpit model was constructed in which the position of the controls could be adjusted. The force exerted by the pilot was measured by means of strain gauges.

Positions of comfort for the pilot are not necessarily ones in which he can apply the most force to the controls.

Notes on the Technique of Landing Airplanes Equipped with Wing Flaps. (M. N. Gough, N.A.C.A. Tech. Note No. 553, Jan., 1936.) (752 U.S.A.)

In connection with the use of flaps the following points are of chief importance:—

(1) Willingness by the pilot to accept steep nose down attitude of machine.
(2) Maintenance of sufficient margin of speed above stall.
(3) A decisive use of control at the proper time.

The Problem of High-Speed Aviation. (R. Leduc and J. Villey, Comptes Rendus, Vol. 202, No. 6, 10/2/36, pp. 461-463.) (808 France.)

Supersonic speeds require impracticable wing shapes (razor blades) quite apart from the serious difficulty of temperature rise due to air friction. With orthodox wing shapes and present-day engine weights it can be shown that consideration of useful load puts an upper limit to flying speeds at about 500 miles/hour. The authors consider jet propulsion as the only feasible solution, the nozzle forming part of the wing surface.

The Security of an Aeroplane when Meeting a Vertical Gust. (G. A. Crocco, Z. Mech., Vol. 4, No. 2, 22/2/36, p. 85.) (872 Germany.)

Sudden gusts are usually rendered visible by the accompanying cloud formation. An elastic wing suspension to allow the incidence to vary under excessive lifts is recommended.

Effect of Tip Shape and Dihedral on Lateral Stability Characteristics. (J. A. Shortal, N.A.C.A. Report No. 548, 1935.) (893 U.S.A.)

Tests were conducted in the N.A.C.A. 7 by 10-foot wind tunnel to determine the effect of wing-tip shape and dihedral on some of the aerodynamic characteristics of Clark R wings that affect the performance of and lateral stability of airplanes.

The tests showed that the plan form of a wing tip as well as the elevation shape had considerable effect on the rate of change of rolling and yawing moment coefficients with angle of yaw.

Armaments

Employment of Conical Bore Gun and Rifle Barrels. (K. Justrow, Z.V.D.I., Vol. 79, No. 47, 23/11/35, pp. 1417-1419.) (357 Germany.)

Although conical bores possess certain theoretical advantages, which have to some extent been verified by experiment, the author is of the opinion that constructional difficulties far outweigh these.

It would be better to concentrate on perfecting the cylindrical bore weapon.

Reference is made to the so-called electromagnetic gun (an American proposal), in which the projectile is accelerated by a series of magnetic fields. The large electric energy required obviously rules out mobility of the gun in this scheme. The absence of noise and flash would render such a gun very difficult to spot

(In course of translation.)

Methods of Attack Against Bombers. (G. Sisti, Riv. Aeron., Vol. 11, No. 11, Nov., 1935, pp. 214-222.) (409A Italy.)

Reference is made to Capt. Vanin's article (translation No. 266). Attack by single-seater aircraft is first considered. High explosive bombs of 5, 10, 15 or 20 kg. are recommended, as well as splinter bombs of 0.5, 1 and 2 kg. " Chained projectiles " are also mentioned. Sighting is by means of a camera obscura placed in the bottom of the cockpit of the leader. Release is co-ordinated by wireless.

To get best results, a passenger should be carried and the attack carried out by means of specially designed aircraft, fitted with armour plating on its under surface. This aircraft, whilst only slightly inferior to the single-seater fighter in speed and climb, can carry a greater weight of bombs and can approach much closer to the bombing formation. As the sighting is now done by the observer a telescopic sight can be employed instead of the rather troublesome camera obscura.

Modern Warship Design—Arrangement of Armour Plating. (W.R.H., Vol. 16, No. 22, 15/11/35, pp. 355-356; *with Special Reference to Bombing Attack,* No. 23, 1/12/35, pp. 369-370; and No. 24, 15/12/35, pp. 378-379, *with Special Reference to Under Water Explosions.*) (417 Germany.)

As the total weight of armour is usually fixed, it is a question of so distributing it as to give maximum protection against various forms of attack.

Till recently first consideration was given to more or less horizontal shell fire above the water line and to torpedo attack.

With increasing range, some form of deck protection against oblique shell fire became necessary.

To this now has become added the need of protection against heavy bomb attack.

It is best to split up the armour protection over at least two decks, the top deck being the thicker plating (60 m./m.) the lower acting as a splinter protection (20 m./m.). This will suffice against bombs up to 1,000 kg. weight.

The writer is of the opinion that bombs of 2,000 kg. will soon become available in which case no existing ship will resist a direct hit.

It is reckoned that such a bomb dropped from 4,000 m. will hit the deck at 200 m./s. and possess a kinetic energy of over 4×10^6 kg. m., sufficient to perforate 100 m./m. of armour plating.

Bombs for this kind of duty will have to be specially designed and the casing stiffened.

Defence against bombs and projectiles, apart from thickness of plating, depends also on angle of impact.

Oblique angle causes a distribution of stress over very much greater areas, and this reduces risk of perforation.

Even if perforation ensues, the path of the projectile becomes refracted and can thus be guided away from vital parts.

As for under water bomb attacks, the method of defence is becoming standardised and the danger is no longer great.

It is usual to fit an outer skin which acts as receiver, followed by an expansion chamber which will take up the force of the explosion.

Of great importance is also the design of the ship's structure in helping absorption.

Modern American design is considered to be exemplary in this.

A fact of great importance is the possible resistance of the ship to repeated under water attack after the outer skin has been damaged.

Protection Against Air Attacks by Town Planning. (Z.V.D.I., Vol. 79, No. 50, 14/12/35, p. 1492.) (471 Germany.)

Main streets should be in the direction of prevailing winds and at least as wide as the sum of the building heights. All buildings likely to be attacked should be isolated. Ornamental lakes and fountains should be provided to assist fire-fighting. Chemical appliances should be available. Alternative sanitary appliances should be available in case of shortage of water supply. Important government offices should be duplicated so that skeleton staff can carry on. Provision should be made along the railway line so that trains can be side-tracked and unloaded irrespective of stations and traffic.

On a Rapid Method of Detecting Presence of Poison Gas (Chemical Warfare). (A. Kling and M. Rouilly, Comptes Rendus, Vol. 201, No. 26, 23/12/35, pp. 1373-1375.) (547 France.)

The suspected air is bubbled through distilled water containing bromothymol blue as indicator. If no discolouration takes place after the passage of 10 litres, the air is considered safe. A violet discolouration indicates danger.

Protection of Daylight Bombing Planes. (Commandant Moineville, Rev. de l'Arm. de l'Air, No. 77, Dec., 1935, p. 1332.) (587 France.)

The author suggests that the squadron operates at a low altitude (50 m.) and is guided by " flotilla leaders " operating above them (1,500 m.).

Official Doctrines of French Military Aviation. (P. Etienne, Rev. de l'Arm. de l'Air, No. 79, February, 1936, pp. 123-129.) (894 France.)

The main consideration is speed. Pride of place is therefore given to single-seater fighter and two-seater light bomber. The number of different types should be restricted to the utmost.

The Bombardment of Ships. (Lt. Aussenac, Rev. de l'Arm. de l'Air, No. 79, February, 1936, pp. 130-136.) (895 France.)

The sighting problems of attack (bombing) and defence (anti-aircraft gunnery) are similar, with the important difference that generally the gunnery officer gets his observation quicker and disposes of practically unlimited ammunition. Low altitude bombing is thus extremely dangerous for the aircraft. This has led to the development of special sights which enable the pilot to take readings at altitude whilst still changing course and only settling down to steady conditions a few seconds before release of the bomb. (See L'Aeronautique, No. 179, p. 77.) This method will, however, only pay against large ships which cannot change course quickly. Small surface craft are practically invulnerable.

Fixing the Position of Aircraft at a Given Instant. Measurement of Speed and Application to Bombing Practice. (Capt. Vauzou, Rev. de l'Arm. de l'Air, No. 79, February, 1936, pp. 137-166.) (896 France.)

The S.O.M. photo-theodolite is described in detail. The aircraft is photographed from the ground, the photographic plates being horizontal and the optical axis of the camera, vertical. Two or three views are taken simultaneously, the relative positions of the photographic plates on the ground being accurately co-ordinated. The plate is measured up by means of a micrometer and finally superposed stereoscopically. Wind speed is measured from the readings by means of $TiCl_4$ smoke clouds. Tables show the consistency of the measurements. The corrected barograph height differs from the true (stereoscopic) height by as much as 100 m. in 3,000 m. By using the known span of the aircraft, the calculation is simplified and the height estimated to within 40 m. at 3,000 m.

(To be continued.)

The Effect of Under Water Explosions. (A. Haid and A. Schmidt, Zeitschrift f.d. gesamte Schiess and Sprengstoffwesen, Vol. 30, No. 8, August, 1935, pp. 229/233.) (917 Germany.)

There are two principal effects—impact of pressure wave followed by impact of water masses disturbed by expansion of gas sphere.

The pressure wave effect depends primarily on the distance between obstacle and explosive.

The strength of the water impact, however, depends not only on the distance from the explosive, but also on the distance of the free water surface which acts as a "vent."

The greater the exploded charge, the deeper therefore it has to be fired in order to obtain max. destructive effect.

The following examples are given:—

Weight of charge (kg.)	13	66	180	375
Depth in metres ...	5	10	15	20

Fuels and Lubricants

Variation of Detonation Spectra with the Nature of the Surrounding Gas. (A. Michel-Levy and H. Muraour, Comptes Rendus, Vol. 201, No. 19, 4/11/35, pp. 828-830.) (170 France.)

A mixture of tetranitro methane and toluene was detonated in the presence of various gases (air, N_2, O_2, Cl_2, H_2, Ar, Kr, etc.).

The detonation wave activates the surrounding gas and the explosion yields a spectrum which varies from case to case. The nature and extent of the spectrum indicates that the source of the radiation is mainly thermal (sudden compression of gas by shock wave).

Relation of Power to Anti-Knock Fuel Requirements for Multi-Cylinder Engines. (S. D. Rubenz, J. Frank. Inst., Vol. 220, Nos. 5 and 6, 1935, pp. 615-656, 755-788.) (221 U.S.A.)

Assuring adequate mechanical strength, the power output of an engine is limited by two factors: Preignition and detonation.

In this article, the author only considers the second of these factors and concludes that the suitability of a given fuel for a given multi-cylinder engine can only be determined by tests in that engine.

It is generally recognised that the onset of detonation is largely governed by the thermal state of the mechanism exposed to the combustion and the author's conclusions amount to saying that single cylinder tests cannot be controlled in such a way as to ensure correspondence with the full-scale engine under service conditions.

As an example, the case of the supercharged engines is taken where the conditions of induction on the single cylinder are generally quite different to those existing in the complete engine.

Difficulties are especially marked in the case of the air-cooled engine, the thermal state of which is very sensitive.

The lack of suitable instruments to record the onset of detonation directly is seriously felt. It is usual to rely on temperature measurements, but these cannot be applied to such vital parts as the valves and piston.

Taking cylinder head temperature as a criterion, the author concludes that in any given engine operated at constant speed and full throttle the rate at which this temperature increases with decrease in mixture strength between the limit of slightly over-rich and best economy is the same for all fuels which do not detonate.

As soon as detonation sets in, the rate increases and varies with the severity of the detonation.

The type of spark play does not apparently affect these conclusions materially.

Lubricants with Corrosion-Inhibiting Properties. (C. M. and S. O. H. Clementson, Chem. and Ind., Vol. 54, No. 47, 22/11/35, p. 1034.) (229 Great Britain.)

Corrosion in engine cylinders is prevented by mixing with the lubricating oil a solution of an alkali peroxide in an alcohol, *e.g.*, Na_2O_2 in MeOH, together with a stabilising agent such as cresol.

Combustion of Gas Mixtures on the Surface of Heated Metals. (Z.V.D.I., Vol. 79, No. 46, 16/11/35, pp. 1399-1400.) (257 Germany.)

A critical review of the work of Davis and Langmuir (England).

In the immediate neighbourhood of the heated wire, the strength of weak gas mixtures is further reduced by surface combustion. The combustion does not spread until the gas at some distance from the wire has been raised to the ignition temperature. This may require a considerable excess in wire temperature over the normal ignition temperature of the gas mixture.

Joint Meeting of the American Petroleum Institute and Society of Automotive Engineers (Nov., 1935). (Autom. Indust., Vol. 73, No. 22, 30/11/35, pp. 720-734.) (298 U.S.A.)

The following general conclusions may be drawn from the papers discussed:—

1. *Oil Testing.*—"Almost anything can be proved about almost any compounded product by selection of method of test and it is likely to be many years before the subject is clarified to a point where we can be really sure of our conclusions."

2. *Liquefied Gas Fuels.*—Extensive use is made of liquid butane and butane/propane mixture for truck propulsion in California and other parts of the coast. Such fuels are cheap and tar free and have shown desirable characteristics apart from cost. The distribution of the dry gas is very good and lean mixtures can be employed.
3. *Diesel Engined Trucks.*—First cost, heavy oil consumption and much higher repair costs hinder development.
4. *Petrol Car Operation.*—High volatility fuel is an advantage, provided vapour lock is guarded against. Low viscosity oils reduce ring sticking.
5. *Knock Rating Procedure.*—A modified bouncing pin is centred both on the diaphragm and on the contact blade. This renders the bouncing more free and improves consistency of method.

A Comparison of Fuel Sprays from Several Types of Injection Nozzles. (D. W. Lee, N.A.C.A. Report No. 520, 1935.) (342 U.S.A.)

Tests were made on 14 nozzles of nine commercial types, the spray being injected into still air at room temperature and various pressures. The sprays were photographed at the rate of 2,000 sec. and impressions on plasticine targets were also taken.

The following general conclusions can be drawn:—

1. *Plain Jet*—drop size variable—require high air speeds for break up—most used in two-stage ignition engines.
2. *Impinging Jets*—small drops—low penetration—useful for spark ignition engines (injection during induction or early compression stroke).
3. *Pintle Jets.*—These jets give a uniform spray with a greater proportion of solid care than the plain hole jets. The shape can be controlled over certain limits by the amount of needle lift and thus accommodated to requirements. This type of jet is in general use for high-speed engines.
4. *Slit Jets*—of limited penetration but great directive power. The slits are sensitive to corrosion, erosion and carbon deposits.
5. *Centrifugal Jets.*—The jet passage is grooved—not worth the extra complication.
6. *Effect of Air Pressure.*—Increase of air pressure from 1 to 14 atmospheres approximately halves the penetration in the early stages. (In the case of the pintle nozzle the effect of pressure is considerably less.)

There are 35 references to other work, from which the following additional conclusions are drawn:—

7. *Effect of Air Speed.*—Air moving at 50 feet/sec. will blow the envelope away from the core during the injection period and will help to distribute all the fuel throughout the combustion chamber after injection cut off. Air speeds of the order of 300 feet/sec. are required to break up the core during the injection period.
8. Spray tip penetration is considerably reduced by heating the fuel, and to a less extent by heating the air.
9. The average drop diameter increases with increase in fuel viscosity and surface tension.

Discussion on Fuel at Pacific Coast Meeting of S.A.E. (J.S.A.E., Vol. 37, No. 6, Dec., 1935, pp. 32-38.) (355 U.S.A.)

1. In the laboratory engines can be run with specific fuel consumption of 0.40. Pan American Air Line has been able to cruise at 0.48. An engine, fuel or carburettor that would reduce the practical consumption to the order of 0.42 would profoundly affect the financial position of any air line.

2. Ring sticking on high output engine of the type used on the " China Clipper " is somewhat of a problem.
3. From experience in maintaining privately owned aeroplanes, much lighter lubricating oils than those normally used are recommended. By reducing oil viscosity, time between overhauls could be extended. Instead of giving top overhauls every 200 hours, a major overhaul every 500 hours is much cheaper.

Effect of Various Additions on the Combustion of Gas Oil in an Injection Engine. (M. Aubert, P. Clerget and R. Duchene, Comptes Rendus, Vol. 201, No. 20, 12th Nov., 1935, pp. 879-881.) (478 France.)

The beneficial effect of additions of alcohol and benzoic aldehyde have already been noted (Comptes Rendus, Vol. 199 (1934), p. 1577). The present paper deals with additions of 25 and 50 per cent. of ethylnitrate to gas oil.

The combustion delay was reduced from 3 to 1 millisecond and the knock was suppressed.

The Dissociation of Carbon Monoxide. (P. Goldfinger and others, Comptes Rendus, Vol. 201, No. 21, 18/11/35, pp. 958-960.) (481 France.)

The energy of dissociation into normal atoms is estimated from spectroscopic data.

Influence of Absorbed Gas on the Boundary on the Chemical Reaction of Oxygen/Hydrogen Mixtures. (M. Prettre, Comptes Rendus, Vol. 201, No. 21, 18/11/35, pp. 962-964.) (482 France.)

Adsorption of water vapour accelerates whilst adsorption of H_2 reduces the rate of reaction of electrolytic gas at 550°C. in glass vessels.

Investigation of Factors Controlling Lubricating Oil Consumptions. (Inst. Autom. Eng., No. 8575B, Class 189, 14/11/35.) (488 Great Britain.)

To obtain consistent results rings must be pegged. For ring gaps pegged either in line on the thrust side or on opposite sides of the piston, oil consumption approximately doubles with a fourfold increase in gap. The pegging on opposite sides gives approximately half the absolute consumption.

The consumption increases proportionally with ring width.

Chemical Constitution and Grading of Engine Fuels. (M. Brutzcus, Comptes Rendus, Vol. 201, No. 7, 12/8/35, pp. 423-425.) (493 France.)

The author proposes to grade fuels according to the increase in the number of molecules brought about by combustion, a large variation being beneficial both from the point of view of specific fuel consumption and freedom from detonation.

Deflagration of Explosive Substance by Supersonic Sound Waves. (M. Marinesco, Comptes Rendus, Vol. 201, No. 24, 9/12/35, pp. 1187-1189.) (545 France.)

The temperature T reached in a supersonic sound wave is given by the expression :—

$$T = A\,(aF)\,(\gamma - 1)/\gamma$$

where A = constant, depending amongst other things on initial temperature and pressure of medium.

a = amplitude of wave.

F = frequency.

By means of powerful quartz oscillators, the author has succeeded in exploding a number of unstable substances such as fulminates, iodides of nitrogen,

peroxides, etc. The substances were immersed in a liquid which did not wet them and the explosion was due to the heating up of the small air bubbles attached. If such bubbles are removed (either by melting or using a liquid which wets the compound), explosions are not obtained.

In certain cases of excessive sensitivity, it was found possible to cause deflagration in the open, without immersion in a liquid.

The effect is rendered more obvious if the supersonic sounds are arranged to cause deflagration in the open, without immersion in a liquid.

Specific Heat, Entropy and Dissociation of Gases and Vapours. (E. Justi and H. Lüder, Forschung, Vol. 6, No. 5, Sept./Oct., 1935, pp. 209-216.) (748 Germany.)

The fundamental thermodynamical relations are written down in terms of the Plank-Boltzmann theory.

The molecular constants are determinable with accuracy from spectroscopic data.

The various characteristics are tabulated for hydrogen, nitrogen, oxygen and oxygen compounds, including carbon and sulphur dioxides.

Twenty-five references.

Detonation Road Tests. 1934 *Report of Co-operative Fuel Research Committee.* (J.S.A.E., Vol. 36, No. 5, May, 1935, pp. 165-179.) (749 U.S.A.)

The road tests are carried out under full throttle conditions and top gear, the car accelerating slowly (going up an incline or towing another vehicle, etc.). The knock intensity produced by various mixtures of the reference fuels at speeds in the range 15 to 50 m.p.h. are determined by ear and compared with the knock intensity produced by the fuel under test at the same intervals of road speed. A reference fuel mixture is formed which develops a maximum knock intensity identical with the maximum knock intensity of the test fuel, irrespective of the speed at which such knock intensities are developed.

By taking a large number of observations on different cars, a fair correspondence between the rating so obtained and that given by the C.F.R. motor method was shown. Individual observations were, however, found to vary erratically up to ± 8 octane number and the above mentioned correspondence can only be obtained by rejecting a certain percentage of the experiments.

It should be pointed out that the tests were carried out on standard cars under normal practical conditions. Neither mixture strength nor mixture temperature is controlled, the adjustment being that specified by the makers. The spark setting employed is generally that giving maximum power and may vary appreciably for different cars.

Under these circumstances the necessity of averaging a large number of determinations is scarcely to be wondered at.

An interesting factor brought out by the tests is the pronounced effect of atmospheric humidity on knocking and this may account for the general improvement of car performance in the evening.

The Detonating Speeds of Various Gas Mixtures. (J. Breton and P. Laffitte, Comptes Rendus, Vol. 202, No. 4, 27/1/36, pp. 316-318.) (811 France.)

Experiments were carried out on propane iso-butane, acetylene, ammonia and other mixtures. Both mixture limits capable of sustaining a detonation wave as well as maximum detonation speed were measured. Additions of small quantities of tetra-ethyl lead had no effect.

*Study of the Extinction of Flame by CC*l4. (C. Dufraisse and J. Le Bras, Comptes Rendus, Vol. 202, No. 3, 20/1/36, pp. 227-230.) (813 France.)

The action of carbon tetrachloride is complex and ranges from simple dilution of oxygen content to certain specific chemical activities. The mechanism of extinguishing a flame after it has been formed is different from the prevention of flame formation and this explains non-correlation of the authors' results with those obtained by bomb explosions.

The Catalytic Combustion of Methane. Part I. (W. Davies, Phil. Mag., Vol. 21, No. 141, March, 1936, pp. 513-531.) (862 Great Britain.)

The results in general lead to the conclusion that the heterogeneous combustion of methane on platinum involves the adsorption of both reactants.

The Use of Alcohol Fuel (Djavol) as a Method of Cooling Aviation Engines. (J. Tourkia, L'Aerophile, Vol. 43, No. 12, pp. 368-371; also Luftwissen, Vol. 3, No. 2, Feb., 1936, p. 51.) (884 France.)

Two kinds of alcohol fuels have been in use for some time in France, the so-called national spirit (50 per cent. alcohol, 50 per cent. petrol) and heavy spirit (25 per cent. alcohol, 75 per cent. high density petrol).

The fuels suffer from a number of defects. The alcohol has to be dehydrated before mixing and the carburation is generally bad. Considerable deposition of liquid fuel takes place on the cylinder walls and this affects the lubrication of the engine deleteriously.

It is claimed by E. Desparmet that an upper cylinder lubricant introduced by him under the name of " anthene " overcomes lubrication difficulties with alcohol fuels and at the same time assists the atomisation of the fuel in the carburettor. It is also suggested that the presence of anthene renders the use of anhydrous alcohol unnecessary.

Mixture of benzol and alcohol containing anthene (0.25 per cent.) are supplied under the trade name " Djavol."

The octane number of such mixture is of the order of 97. Mixed with various proportions of petrol they are said to be stable against water crystallisation down to $-48°C$.

On account of the high latent heat of alcohol mixtures, the cylinder temperatures are lower in spite of increased power output (*i.e.*, increased volumetric efficiency).

Russian Experience with Cracked Spirits. (Abstract: M. Precoul, L'Aerophile, Vol. 43, No. 12, Dec., 1935, pp. 372-373; Luftwissen, Vol. 3, No. 2, Feb., 1936, p. 51.) (885 Germany.)

Considerable quantities of cracked fuel are employed in Russia. They contain a large amount of gum and therefore require stabilisation with phenol. The gum separates out mostly in the induction pipe and round the inlet valve. The fuel has 80 octane number and poor lead response.

Nitration of Gaseous Paraffins. (H. B. Hass, E. B. Hodge and B. M. Vanderbilt, Ind. and Eng. Chem., Vol. 28, No. 3, March, 1936, pp. 339-344.) (902 U.S.A.)

Nitro-methane, nitro-ethane, both nitro-propanes and all four nitro-butanes are readily obtainable. Their low ignition temperature renders them suitable as an addition to Diesel engine fuels.

Engines

Propagation of Combustion in the Diesel Engine. (L. Breves, Forschung, Vol. 6, No. 4, July/Aug., 1935, pp. 183-191.) (152 Germany.)

The experiments were carried out in one of the cylinders of a three-cylinder Krupp two-stroke engine, developing 75 b.h.p. at 500 r.p.m.

The travel of the flame was recorded by a series of ionisation gaps connected to a cathode ray oscillograph.

Combustion starts usually inside the cone of the injected fuel. The ignition lag (*i.e.*, time interval between beginning of injection and first appearance of a flame) depends on type of fuel, load and size of orifice. Injection pressure has only little effect. With diminution of size of orifice of fuel injector, the zone of initial combustion approaches the orifice. The spread of combustion is very uneven and may be extremely rapid in the case of brown coal tar oils. The flame persists longest in the centre of the combustion space and dies out first within the injected fuel cone.

The Measurement of Varying Temperatures in the Cylinder Wall of Piston Engines. (H. Pfriehm, Forschung, Vol. 6, No. 4, 1935, pp. 195-201.) (154 Germany.)

It is pointed out that the presence of insulators round the wires embedded in the cylinder wall may cause considerable errors by distortion of the temperature field (reflection of temperature waves). Such errors depend on the depth of the insulator below the surface and the wave length of the temperature wave. Errors of 20 per cent. are quite common.

A further source of trouble is the Peltier effect exhibited by couples as usually employed.

By restricting the amount of insulator and using two wires arranged concentrically, the author shows how both errors can be kept within small limits.

Evaluation of Variables Influencing Air Cooling of Engines. (K. Campbell, J.S.A.E., Vol. 37, No. 5, Nov., 1935, pp. 401-410.) (219 U.S.A.)

The object of these experiments is to convert cooling results obtained under one set of conditions to equivalent values under other conditions.

The tests were carried out mainly on a single cylinder Wright Whirlwind of modern design CR 7/1, bore 5in., stroke 5½in. fitted with baffles.

Some flight tests using a Cyclone engine were also carried out. Detonation was avoided throughout.

To investigate the thermal state of the cylinder the outside was provided with 36 thermocouples distributed over the head and walls.

The highest temperature recorded was at a place in the cylinder head between the rear plug and the exhaust valve seat. Under normal operative condition, this temperature was app. 480°F. (250°C.), other representative temperatures under similar conditions were as follows:—

Rear spark plug gasket	221°C.
Exhaust valve guide boss	215°C.
Exhaust valve spring seat	176°C.
Mid barrel	165°C.
Exhaust rocker pin	115°C.
Flange (front)	105°C.
Flange (rear)	132°C.

The front spark plug gasket temperature was found to be erratic, but the rear gasket temperature varied in a satisfactory manner with most of the other temperatures and could therefore be used as a standard reference for this cylinder and baffles.

A large number of experiments were carried out to investigate change of cylinder temperature with :—

1. Air speed;
2. Cooling air temperature;
3. Mixture strength;
4. Air intake temperature.

The flow of air through the baffle was also investigated and a flow indicator devised.

It was concluded that :—

1. The difference between air and cylinder temperature varies inversely as the square root of the mass flow of the air, for constant b.h.p. and cooling air temperature.
2. Variation of wall temperature with cooling air temperature is app. linear, but depends markedly on the position of thermocouple.
3. The effect of mixture strength is very pronounced, the temperature of the hottest spot on the head rising from 410°F. to 510°F. as the mixture is progressively weakened from 9/1 to 14/1. (Max. power corresponds to a *MS* 12/1 and temp. 480°F.).
4. An increase in air intake temperature from 60°F. to 212°F. is accompanied by a diminution of 10 per cent. in b.h.p. and a drop of app. 15°F. of cylinder wall temperature.

The effect of change in air speed temperature was also tested in an aeroplane fitted with a cyclone engine. Flights were carried out at five altitudes between 2,000 and 17,500 feet.

The result obtained in this manner departs in some instances considerably from those obtained on the ground, and the temperature difference between wall and cooling air appears to vary inversely as the mass flow rather than as the inverse square root.

It is suggested that the disturbed condition of the cooling air (propeller slipstream) is responsible.

The data published are not sufficient to enable the object of the research, as set out at the beginning of this review, to be realised.

Useful ground work has, however, been covered.

An Analysis of Critical Stresses in Aircraft—Engine Parts. (C. F. Taylor, J.S.A.E., Vol. 37, No. 5, Nov., 1935, pp. 412-418.) (220 U.S.A.)

Critical stresses are generally of a local character and cause failure under fatigue. Our knowedge of the endurance property of various materials is limited to tests on simple forms over limited ranges of local variation with simple types of stresses. In the engine the stresses are complicated, and at the present moment designers have to rely largely on accumulated experience obtained from successful engines and extrapolation has to be done with extreme caution. As a help, the behaviour of certain engine parts in special test plants under conditions simulating practice is of great interest. As the fitting of strain gauges is often difficult on account of the restricted space available, coating the part under test with a brittle enamel has given valuable information as to stress distribution. Fracturing models made of brittle material (plaster of paris) under steady load also simulate fatigue failures of the actual working substance. Similarly, strain distribution in a crankshaft has been studied by means of a rubber model. Such problems are difficult to explore by photo-elastic methods, which are restricted to two-dimensional cases. As a simple example of the utility of such experiments as applied to " scaling-up " of similar parts, fillet radii should be proportional to the other dimensions.

Fourteen references.

Iron and Copper Bonded in Composite Cylinder Heads. (I. E. Aske, Autom. Indust., Vol. 73, No. 22, 30/11/35, pp. 724-733.) (299 U.S.A.)

In a turbulent " L " head the combustion chamber opposite the piston is provided with a cast in copper plug, which projects into the water space.

It is claimed that this cools the charge and delays detonations.

Details of the required casting technique are given.

N.A.C.A. Study of Radial Air-Cooled Engine Cowling and Cooling. (D. H. Wood and C. Kemper, J.S.A.E., Vol. 37, No. 6, Dec., 1935, pp. 441-448.) (353 U.S.A.)

An investigation has been undertaken to determine a rational basis for the design of the N.A.C.A. cowling. The effect of front and of rear opening and shape of cowling on the quantity of air flowing through the cowling, the pressure drop and the drag have been determined from tests in a wind tunnel. The quantity of air and the pressure drop required for satisfactory cooling of a given design of air-cooled cylinder have been determined from tests on a single cylinder. The results obtained from the tests are being checked by large wind tunnel tests on a 550 h.p. engine fitted with propeller. The working of the latter exercises a considerable influence on the quantity of air passing through the cowling, and, when allowance is made for this, the results so far obtained are stated to be in satisfactory agreement with predictions based on model tests.

The following general conclusions can be drawn from the report:—

1. The quantity of heat to be dissipated to the cooling air from a given design of engine cylinder depends mainly on the indicated power output, and is thus the same whether the output is obtained at low engine speeds and high m.e.p. (boost) or high engine speeds and normal m.e.p.
2. The temperature difference between cylinder and air for constant air temperature is inversely proportional to $(P.V.)$ 0.4 to 0.5
   where P = air density
   V = air speed.
3. For constant conditions of engine power, mixture strength, induction temperature and (PV) for a change in 40°C. of cooling air temperature, the following changes in engine temperature can be reckoned with:—

Cylinder head	27°C.
Barrel	25°C.
Flange	15°C.

4. The change in cylinder temperature is usually of the order of 10 per cent. of the change in induction temperature. There are, however, many inconsistencies.
5. The power required for cooling a single cylinder (45 h.p.) by means of a separate blower and jacket amounts to 7 per cent. of the engine output (blower efficiency 50 per cent.).
6. Although the test results for some of the cowlings used are plotted in terms of non-dimensional coefficients, the graphs are marked: " For illustration only—do not use for design."

Evidently considerably more correlation work is required before the design of such cowlings can be put on a " rational basis."

The Electrolytic Cleaning of Exhaust Valves. (S. D. Heron and other, J.S.A.E., Vol. 37, No. 6, Dec., 1935, pp. 19-21.) (354 U.S.A.)

The valve, after a preliminary wash to remove oil, is made the cathode in a bath of fused sodium hydroxide—sodium carbonate. After about five minutes

with a current of 6 amps., all deposits (including those due to leaded fuels) are removed, without attacking any of the underlying metal.

Damping Influences in Torsional Oscillation. (J. F. Shannon, PL. D., Engineering, Vol. 140, No. 3649, 20/12/35, pp. 675-678, and No. 3650, 27/12/35, pp. 702-704.) (394 Great Britain.)

A four-cylinder engine with a two-bearing crankshaft was connected through a length of shafting to an electric motor and rotated at a series of speeds, the cylinder heads being removed.

The oscillation period of the system could be altered by the fixing of additional flywheels.

Vibration diagrams were taken at both ends of the crankshaft by means of a Geigor recorder.

The magnitude of the critical vibration varied in the ratio of 2 : 1, depending on the amount of oil fed to the bearings. A corresponding diminution in the electrical power required to motor the engine at critical speeds was noted.

Friction and Vibration. (H. Bock, Z. Instrum., Vol. 56, No. 2, Feb., 1936, pp. 71-74.) (769 Germany.)

The effect of solid and fluid frictions on the frequency of a mass under spring control undergoing continuous translation is investigated. Interesting examples in practice show the heavy damping brought about by fluid friction.

The Damping Influence of the Propeller during Torsional Oscillations. (H. Guntz Berger, Z. Mech., Vol. 4, No. 2, 22/2/36, p. 67.) (870 Germany.)

The effect of the water flow increases the inertia of the propeller by as much as 60 per cent. instead of the 25 per cent. usually assumed.

The damping moment depends on the angular velocity of the propeller and the speed of the boat, but not on the angular acceleration.

A New Method of Regulating the Output of Centrifugal Blowers. (G. Serragli, L'Aerotecnica, Vol. 15, No. 11-12, 1935, pp. 1068-1079.) (918 Italy.)

The blades are pivoted and fitted with balance weights so that the couple due to centrifugal force tending to open the blades is largely balanced by the couple due to air reaction.

The force required to move the blades is thus limited to overcoming the friction at the pivot.

The scheme in its present form is only applicable to relatively low speed fans fitted with few blades. Its application to aircraft superchargers will present great difficulties on account of the high speed of operation.

If frictional difficulty could be overcome, the variation of density with altitude might be used to govern blade position automatically.

Instruments

The Effect of Air or Instrument Vibration on the Reading of Dynamic Head. (G. Rich, Z.A.M.M., Vol. 15, No. 5, Oct., 1935, pp. 290-299.) (196 Germany.)

On the supposition that the instrument reads the true average of Pv^2 where v is the effective velocity at any instant, expressions for the effect of a vibration in the direction of flow (*i.e.*, along the instrument axis) are easily calculated. The effect of vibrations at right angles to this is complicated by the response varying with the obliquity of the resultant current. This causes the difference in reading between the steady and the vibrating instrument to pass through a maximum value and then decrease, for a gradually increasing amplitude of vibration. For an instrument of the Prandtl design, the maximum difference

in this case amounts to 8 per cent. and occurs at a frequency f given by the relation

$$af/vo = 0.092$$

where a = amplitude of vibration (assumed sinusoidal).
Vo = steady air velocity (if instrument is vibrating).
or = mean value of air velocity (if instrument is stationary and air current is vibrating).

Direct experiment with a vibrating instrument in a wind channel shows a difference of the estimated amount for frequencies up to 25 sec. For higher frequencies experimental values are about double the calculated. The Author attributes this to the following factors which have been neglected in his computation:—

1. Capacity and throttling of pipe line.
2. Instrument does not read true time average ρv^2.

Ultra High Speed Motion Picture Photography. (Ind. and Eng. Chem., Vol. 14, No. 3, 10/2/36, pp. 61-62.) (760 U.S.A.)

Successive pictures are obtained by flashing the source of illumination (5,000 watt mercury vapour lamp) at rates up to 2,000 sec. by means of Thyratron control.

Photographic Registration of Angular Measurements. (K. Ludemann, Z. für Instrumentenkunde, Vol. 56, No. 2, pp. 63-71.) (767 Germany.)

The principles underlying photographic registration are briefly dealt with (balloon theodolites, cine-theodolites, etc.).

A valuable bibliography of 48 references is attached.

The Measurement of Absolute Viscosity. (L. R. Bacon, Journal of Franklin Institute, Vol. 221, No. 2, Feb., 1936, pp. 251-273.) (768 U.S.A.)

The falling sphere viscometer is investigated mathematically and experimentally over the range 7.5 to 3,600 poises.

After applying simple corrections, viscosity to within 1 per cent. of the absolute value obtained by capillary tube method can be realised.

Sixteen references.

New High-Speed Cine Camera. (L. Bull and P. Girard, Comptes Rendus, Vol. 202, No. 7, 17/2/36, pp. 554-555.) (805 France.)

The film is mounted on the inside of a drum which forms part of a pivotless air turbine. Special precautions are taken to ensure stability of operation. Intermittent spark illumination of the object is used, and the image is transferred to the inside of the drum carrying the film by means of a right-angled prism. 50,000 pictures a second each 5 cm.^{2} in area are possible, the film length required being only 22 cm.

Special Conditions Affecting the Use of Electrical Instruments in the Aeroplane. (W. Hofmann and K. Hellwig, Luftwissen, Vol. 3, No. 2, Feb., 1936, pp. 31-39.) (877 Germany.)

Vibration, acceleration and inclination put additional strains on the working of aircraft instruments, and require special design measures. Subsidiary factors are the effects of temperature and stray magnetic fields. Of special importance is the provision of an open scale, since conditions of observation are generally not good. Recent advances in magnetic Al. Ni. alloys have helped here, and the use of alternating current instruments wherever possible is also recommended (revolution counters). In their present form these instruments are difficult to compensate for temperature effects.

American Opinion Concerning Electric and Wireless Installation in Aircraft. (Luftwissen, Vol. 3, No. 2, Feb., 1936, p. 43.) (879 Germany.)

All engine accessories should be driven by the main engine direct. Other accessories should be supplied with independent power supply (auxiliary engine of suitable size).

As regards directional apparatus, the ground-operated beacon is preferred to the direction finder installed in the machine. The latter requires very careful installation to ensure absence of disturbances by other electrical circuits on the machine. Static charges produced on the outside antenna (especially in winter during gales) present a serious problem.

Echo Sounding—the C.E.M.A. Apparatus. (J. Routhier, Luftwissen, Vol. 3, No. 2, Feb., 1936, p. 49.) (880 Germany.)

The instrument has passed French Air Ministry acceptance tests. Time measurement is correct to 0.006 sec., and the instrument deals either with the range 5/40 m. or 30/250 m. The dimensions of both sender and receiver are approximately 60 × 30 × 30 cm.

Non-Magnetic Headphones. (Abstract from Aviation, Vol. 35, No. 1, Jan., 1936, p. 44; Luftwissen, Vol. 3, No. 2, Feb., 1936, p. 49.) (881 Germany.)

The headphones made by the American Brush Development Co. work on the pilzoelectric principle. There is thus no magnetic interference with other sensitive recording instruments.

Vibration Recorders and Accelerometers. (H. W. Kock, Luftwissen, Vol. 3, No. 2, Feb., 1936, pp. 55-56.) (886 Germany.)

The vibration recorders are intended for the study of the motion of structures as a whole.

Accelerometers are more often used to study the motion of isolated parts. In the latter case it is essential that the fixing of the apparatus does not seriously affect the motion.

A type of accelerometer is described in which the relative motion of the inertia mass affects the delivery of an air jet and can thus be recorded on a pressure gauge. Other types depend on the principle of the carbon microphone.

Materials and Elasticity

The Fracture of Rotating Discs of Brittle Material. (H. Schlechtweg, Ing. Arch., Vol. 6, Part 5 (Oct.), 1935, pp. 365-372.) (204 Germany.)

Every change in shape of a working substance can be considered as made up of two parts—a change in volume and a shear. In the case of brittle materials under practical conditions, it can be assumed that the change in volume is related to the hydrostatic pressure or tension in the same way as for bodies obeying a linear elastic law. The resulting shear strains in brittle bodies are, however, no longer related to the shear stresses by a constant shear coefficient, but the relationship depends on the existing tensile force distribution.

The author derives a number of new elastic constants which he defines as the "sensitivity" of the brittle working substance as regards tension, shear and pressure.

He then obtained an expression for the limiting safe speed as a linear function of these constants and the dimensional characteristics of the disc. It is of interest to note that a rotating wheel is loaded much more uniformly in the case of a brittle substance than if Hooke's law is obeyed. American experiments on emery wheels fit the calculated curve.

An Investigation of the Compressive Strength Properties of Stainless Steel Sheet-Stringer Combinations. (A.C.I.C., Vol. 7, No. 697, 30/11/34.) (390 U.S.A.)

For such data as were available the linear relationship between load carried and stiffener units, and independence from stiffener pitch applies as well to aluminium alloy plate stringer combinations.

The present specification for the strength of spot welds is not adequate to prevent failures of the type experienced during these tests. It is felt that it should be amended by a requirement to the effect that the weld strength of built-up sections be demonstrated by test to be sufficient to allow complete collapse, or crushing, of the section without weld failures.

Study of Intercrystalline Corrosion by Diffused Reflection of Light. (M. F. Carrac, Comptes Rendus, Vol. 201, No. 5, 29/7/35, p. 330.) (490 France.)

The amount of reflected light depends on the angle of incidence and the dimensions of the surface groove caused by pitting. In the case of dural the curve connecting intensity and time goes through a maximum and then approaches a constant (low) valve. The maximum is reached at the same time for all angles of incidence of illumination, the absolute values of the reflected light diminish, however, with increasing obliquity of the incident light.

The final constant value reached is connected in a simple manner with the dimensions of the surface groove.

Modulus of Elasticity of Materials for Small Stresses. (R. H. Evans and R. H. Wood, Phil. Mag., Vol. 21, No. 138, Jan., 1936, pp. 65-80.) (496 Great Britain.)

The materials tested consisted of steel, cast iron, glass, slate, marble, granite, sandstone and concrete.

The test piece was in the form of a column, 3cin. long and 2 sq. in. cross-section.

Strains of the order of 10^{-6} inches could be measured by means of special mirror extensometers.

All the curves showed a sharp rise of the value of E as the range of applied stresses is increased from zero. Explanations on the basis of combined elastic and viscous force having failed, the authors suggest the presence of initial stresses (both tensile and compressive) as a possible cause.

Stability of Bars with Lateral and Axial Loading. (W. Way, J. Aer. Sci., Vol. 3, No. 2, Nov., 1935, pp. 46-51.) (522 U.S.A.)

In this paper a method of calculating critical loads is used which involves applying an auxiliary moment M at one point of the structure, calculating the resulting rotation θ, and equating to zero the derivative $dM/d\theta$. This method makes it possible to easily investigate certain modes of buckling that would otherwise be apt to escape attention, as the unsymmetrical buckling of a uniformly loaded bar of two equal spans with axial load.

The critical end load for a one or two-span strut with lateral load is found to be independent of the lateral load. For a two-span strut, the critical load is found to lie between the Euler loads for the long and short span separately.

Two new problems are taken up. One is that of a two-bay strut with rotationally elastic middle support. The critical load varies from the value for a simple two-bay strut when the spring constant is zero to the value for the strut with locked middle joint when the spring constant is infinite. The other new problem is that of a straight bar buckled to an arch and supporting lateral load on the convex side. The ends are held a fixed distance apart, and the problem is to find the lateral load necessary to cause collapse. It is found that

$Lq_{cr} = 23.2\ P_{eu}a/L$ where q_{cr} is the intensity of the critical lateral load, a the initial deflection of the buckled bar, L the length and P_{eu} the Euler load for the bar. The arched bar collapses unsymmetrically.

Physical and Metallurgical Properties of Lead-Calcium Alloys for Storage Cells. (E. E. Schumacher and G. S. Phipps, Bell Tele. Pub. No. B.884, Oct., 1935.) (619 U.S.A.)

Lead-calcium alloys containing from 0.04 to 0.10 per cent. calcium have combined physical, metallurgical, and electro-chemical properties which recommend them as a superior material for storage cell grids and plates. Batteries containing elements made of these alloys, when properly heat-treated, should have a high efficiency and long service life. These new alloys can be satisfactorily cast, rolled, welded, machined, and burned.

Nitriding of Austenitic Steels. (B. Jones, Met. Prog., Vol. 29, No. 2, Feb., 1936, p. 39.) (763 U.S.A.)

The hardening effect due to nitriding varies considerably with the composition of the steel and temperature as well as pressure of gas. Valve stems (heat resisting Cr-Ni steels) offer a new field of application.

Photo-Elastic Study of Stresses Due to Impact. (Z. Tuzi and M. Nisida, Phil. Mag., Vol. 21, No. 140, Suppt., Feb., 1936, pp. 448-473.) (860 Great Britain.)

To analyse quick variations of internal stresses, *e.g.*, in vibrating specimens or in impact phenomena, kinematography or photo-elastic fringes at very high speeds was devised. As the light source, an ordinary carbon arc lamp has been used with heavy current and with a red filter, selecting a very narrow band.

The study was limited to a certain section and an exposure of about 1/5,000-1/50,000 sec. has been achieved.

Subsidiary Whirling of Rotors Due to Speed Oscillation. (D. Robertson, Phil. Mag., Vol. 21, No. 140, Suppt., Feb., 1936, pp. 474-501.) (861 Great Britain.)

Whirling of a shaft is most commonly caused by unbalance, but it may also be produced in a number of other ways. By itself speed oscillation is not a source of whirling, but it does induce additional subsidiary whirls in a rotor which already has an unbalanced whirl. These subsidiary whirls are usually quite small.

Meteorology and Physiology

Physiology and Mechanical Flight. (M. Tricot, L'Aerophile, Vol. 43, No. 11, Nov., 1935, pp. 325-329.) (331 France.)

A plea is entered for a more extensive study of animal flight. A bird's wing exercises a forward thrust both on the up and down stroke. This appears to be closely related to wing curvature and the shape of the wing roots (body fairing). The interaction of body and wing produces a complicated system of airflow which requires further study.

Ice Formation on Aeroplanes. (H. Noth and W. Polte, Luftwissen, Vol. 2, No. 11, Nov., 1935, pp. 304-311.) (336 Germany.)

Meteorological conditions likely to produce ice formation are described and possible precautions in mapping out a flight are detailed.

The considerations only apply to Mid-European conditions. In these regions, a cloud formation resembling high altitude fog is often associated with regions

of high pressure during winter. Clouds are seldom higher than 6,000 feet and super-cooled rain is likely to be met with. This condition is the most dangerous for ice formation on aircraft.

(See Translation No. 286.)

A Subjective Photometer. (W. D. Wright and J. H. Nelson, J. Sci. Inst., Vol. 12, No. 12, Dec., 1935, pp. 373-377.) (391 Great Britain.)

The object of the photometer is to measure the variation of sensitivity of the eye for different conditions of the visual mechanism and the principle employed is that of binocular matching, in which a patch viewed in the left eye is compared in intensity with a similar patch viewed in the right eye. A calibrated photometer wedge provides the necessary intensity control. Applications of the apparatus include measurements on the effect of adaptation and on the extent of the loss of vision in cases of uniocular blindness.

The Theory of General Circulation Applied to the Temperature Distribution of the Atmosphere. (G. Debebant and others, Comptes Rendus, Vol. 201, No. 5, 29/7/35, p. 346.) (491 France.)

The author had previously applied the condition of minimum dissipation to the study of solar problems. (Comptes Rendus, Vol. 199, 1934, p. 1287.) A similar method applied to the configuration of the atmosphere leads to expressions for the variation of temperature with height for the troposphere and stratosphere which are in general agreement with experimental data.

Condensation Nuclei and Particles in Suspension in the Atmosphere. (O. Thellier, Comptes Rendus, Vol. 201, No. 5, 29/7/35, p. 348.) (492 France.)

Condensation nuclei and suspended particles were measured by the methods of Aitken and Owens respectively. The average number of nuclei per cc. of air in Paris is of the order of 60,000, whilst the particles in suspension are very much less (order of 100-600).

Whilst the nuclei do not show any regular variation, the suspended particles undergo well marked diurnal and seasonal changes and also determine atmospheric visibility.

A Practical System for Radiometeorography. (L. F. Curtiss and A. V. Astin, J. Aer. Sci., Vol. 3, No. 2, Nov., 1935, pp. 35-39.) (520 U.S.A.)

A description is given of a complete system based on the Olland telemeteorograph, for obtaining meteorological and similar data from instruments attached to sounding balloons by means of a radio transmitter. In this way records are obtained instantaneously by a receiver located on the ground. A wave length of 5 metres is used permitting convenient use of half-wave tuned doublet antennas for transmission as well as reception. The radio transmitter is " keyed " in such a way that signals are emitted only during several short contacts per minute, thus greatly reducing the size of the plate batteries required. Complete apparatus for attachment to balloon weighs less than 2lbs. and has been received clearly at altitudes of 23 kilometres (14.3 miles) and at distances of 80 miles. A method of direction finding for pulses used in this system is described.

The General Circulation Theory Applied to the Atmosphere—the Law of Rotation and the Field of Pressure. (G. Debebant and others, Comptes Rendus, Vol. 201, No. 8, 19/8/35, pp. 453-456.) (543 France.)

On the basis of minimum thermal dissipation the authors have previously obtained expressions for the temperature distribution in the atmosphere (Abstract No. 103).

Using the principle of minimum mechanical dissipation, expressions are obtained for the pressure distribution and direction of prevailing winds for various altitudes and latitudes. The authors claim satisfactory agreement with observations.

The Tyndallometer—a New Instrument for Rapid Measurement of Atmospheric Dust Content. (M. Bereck, K. Marmichen and W. Schafer, Z. für Instrumentenkunde, Vol. 56, No. 2, pp. 49-56.) (766 Germany.)

The instrument made by Leitz depends on the scattering of light by dust particles, and enables rapid variations to be followed.

The apparatus is very compact and easily carried by the observer.

Fifteen references.

Directed Vision. (Y. Le Grand, Comptes Rendus, Vol. 202, No. 7, 17/2/36, pp. 592-594.) (807 France.)

The resolving power of the human eye diminishes rapidly with illumination. This is mainly due to losses between lens and retina. These losses vary considerably with the optical path and the author describes various methods of investigation.

Variation of Smoke and Dust Content of Town Air. (R. Herman-Montague and L. Herman, Comptes Rendus, Vol. 202, No. 6, 10/2/36, pp. 501-503.) (810 France.)

Experiments were carried out at Lyons, using an Owens apparatus. The results are very similar to those obtained in London. Tests carried out in Berlin show considerably less dust in the afternoon.

Method for the Rapid Determination of CO_2 Content of Atmospheric Air. (A. Kling and M. Rouilly, Comptes Rendus, Vol. 202, No. 4, 27/1/36, pp. 318-320.) (812 France.)

The air is bubbled at a fixed rate through a standard caustic soda solution treated with phenol thalein. The volume of air required to cause the indicator to react is proportional to the CO_2 content.

Miscellaneous

A Method of Numerical Solution of Differential Equations. (V. M. Faulkner, Phil. Mag., Vol. 21, No. 141, March, 1936, pp. 624-640.) (804 Great Britain.)

A modification of the Adams method for the solution of certain non-linear differential equations is described. The following advantages are claimed:—

1. Increased accuracy with the use of differences up to the same order.
2. An indication of the accuracy of the integrators is possible.

Upkeep Overhaul in French Civil Aviation. (Luftwissen, Vol. 3, No. 2, Feb., 1936, p. 39.) (878 Germany.)

The Government has delegated the control of all civil aircraft to the aeronautical section of the Bureau Veritas, which body keeps representatives on all the larger aerodromes. The officials have entry to all repair shops and are specially requested to watch that during overhaul no unauthorised changes are carried out.

As far as engines are concerned, the tendency is to cut out top overhauls as much as possible and have complete overhauls at stated intervals. These depend on the design of the engine and its particular use.

The Process of Parachuting. (Abstract: P. A. Richard, L'Aérophile, Vol. 43, No. 12, Dec., 1935, pp. 357-367; Luftwissen, Vol. 3, No. 2, Feb., 1936, pp. 51-52.) (887 Germany.)

A good parachute should have a time of opening of 2 to 3 seconds and a terminal velocity of 5 m./sec. This entails deceleration of the order of 7 g. which can be borne by the human organism without deleterious after effects. Immediately after landing, however, beginners show high blood pressure and considerable excitement. The free drop stage before opening of parachute is generally completely forgotten.

When fully open the parachute has a resistance coefficient of the order of 1.3.

Long-legged individuals have a distinct advantage in reducing landing impact.

Seaplanes

Tank Tests of Three Models of Flying Boat Hulls of the Pointed-Step Type with Different Angles of Dead Rise—N.A.C.A. Model 35 Series. (J. R. Dawson, N.A.C.A. Tech. Note No. 551, Jan., 1936.) (751 U.S.A.)

The pointed-step type hull irrespective of angles of V (or dead rise) is especially suited for seaplanes with high get-away speeds.

Research in the R.A.E. Tank. (L. C. Coombs, Z. Mech., Vol. 4, No. 2, 22/2/36, pp. 87-88.) (873 Great Britain.)

Reference is made to the effect of wing stubs on flying boat resistance. The position of the wing stub is of great importance, since it may be subject to wave and spray action during the take-off.

If properly placed, stubs of the type fitted to the Dornier boats add very little to the hydrodynamic resistance. Wind tunnel tests show that they can add appreciably to the aerodynamic lift when the machine is airborne.

Seaplane Take-off Weights. Parts I, II and III. (E. T. Jones, Z. Mech., Vol. 4, No. 2, 22/2/36, pp. 88-90.) (874 Great Britain.)

The importance of a suitable compromise between the requirements for top speed and those for highest possible lift for take-off is stressed.

The optimum wing setting considering take-off only is of the order of 12°. This would entail a very high drag of the float when airborne.

The provision of split flaps or sliding hinge bellows capable of quick movement when unsticking is recommended

Variable pitch airscrews require modified hull design in order to become effective.

The effect of wind can generally be allowed for with fair accuracy. The effect of surface roughness of the water is difficult to assess.

Take-off Performance of Flying Boats. (A. Gassner, Aero Digest, Vol. 27, No. 5, pp. 24-25.) (882 U.S.A.)

Important factors influencing take-off are wing setting and trim, and the ratio of flying weight to the third power of the maximum boat width. A rapid unsticking requires at least 25 per cent. excess of thrust over water resistance. Seven representative American flying boats, including the Douglas Dolphin are considered. These range in gross weight from 10,000 to 50,000lbs.

The Reduction of Ships' Resistance by the Lift of Supporting Surface (Hydrovanes). (W. Graff, Werft-Reederei-Hafen, 1935, No. 22, pp. 334-338.) (916 Germany.)

In the case of a wing, the ratio of drag to lift is equal to the tangent of the gliding angle and is designated by E.

In the case of a ship, a similar expression can be obtained for the ratio of resistance to displacement $W/D = E^1$.

It is obvious that a combination of ship and hydrovane can only reduce the overall resistance to propulsion if E^1 for the normal ship is $> E$ for hydrovane.

Values of E^1 for various types of surface craft under various operative conditions are known to vary app. as v^2/l where l is the cube root of the displacement. Generally speaking, E^1 is less than 0.08 (ocean liner, cruiser, torpedo boat, cargo boat).

Values of E, on the other hand, do not vary much with speed and dimension of wing so long as incidence is constant and favourable. The values are, however, affected considerably by interference with the hull and drag of supports.

A lower limit for E appears to be 0.08, which happens to be the upper limit for the usual ship construction.

From this it follows that the fitting of hydrovanes is only profitable for high speed surface craft of relatively small dimensions. Torpedo boats are too large to benefit.

The author works out the case of a 30-ton speed boat running at 50 knots. Without hydrovanes this boat requires over 1,000 h.p. If the hull is lifted out of the water by means of the vanes, only 600 h.p. are required for the same speed.

In order to get the boat to unstick, however, at least 700 h.p. are required, the h.p. diminishing rapidly to 600 as the boat hull lifts clear.

This power reserve could be reduced if the angle of incidence of the hydrovanes could be altered so as to lift the boat at a lower speed. Apart from mechanical difficulties, this introduces the danger of cavitation.

From the shape of the power curves it appears that hydrovane boats can only be justified if operated at maximum speeds. At intermediate speeds the boat may take considerably more power than a normal boat. If, therefore, a large speed range is required, it is essential to provide some method of folding up the hydrovane surfaces.

Wind Channels

Tests in the Variable-Density Wind Tunnel of Related Airfoils having the Maximum Camber Unusually Far Forward. (E. N. Jacobs and R. M. Pinkerton, N.A.C.A. Report No. 537, 1935.) (416 U.S.A.)

A family of related airfoils having the position of maximum camber unusually far forward was investigated in the variable-density tunnel as an extension of the study recently completed of a large number of related airfoils. The new airfoils gave improved characteristics over those previously investigated, especially in regard to the pitching moment. Some of the new sections are markedly superior to well-known and commonly used sections and should replace them in application, requiring a slightly cambered section of moderate thickness, having a small pitching moment coefficient.

Wind Tunnel Tests of a 10-foot Diameter Gyroplane Rotor. (J. B. Wheatley and C. Bioletti, N.A.C.A. Report No. 536, 1935.) (435 U.S.A.)

1. The model tests, because of the excessive size of the rotor hub, are unreliable as regards the lift-drag ratio of a gyroplane rotor.
2. The pitch setting is the critical parameter that determines rotor characteristics.

3. A change in solidity causes a proportional change in rotor force coefficients only at high tip-speed ratios.
4. The rate of change of rolling moment with feathering angle is not materially influenced by pitch angle or solidity and decreases dangerously at low tip-speed ratios.
5. The maximum resultant force coefficient is obtained with a pitch setting of 5°.
6. A feathering angle considerably greater than 10° is required to obtain zero rolling moment at high tip-speed ratios for pitch settings greater than 4°.

The Large Wind Tunnel of Chalais-Meudon. (A. Lapresle, Z. Mech., Vol. 4, No. 2, 22/2/36, p. 72.) (871 Germany.)

The tunnel is of the Eiffel type, using a sealed experimental chamber in which the pressure is below atmospheric.

The jet is 11 m. long and 16×8 m. section. Six fans (10-bladed) are used, absorbing approximately 1,000 h.p. each.

Wireless

Extension of a Previous Formula for Earth Absorption in Wireless Telegraphy. (K. F. Niessen, Ann. d. Phys., Vol. 24, No. 1, Sept., 1935, pp. 31-48.) (100 Germany.)

The author considers the presence of both displacement and conductor currents for various values of the dielectric constant and conductivity of the earth's surface.

If T represents the fraction of the radiated energy absorbed by the ground

$$T = f(n, d, x)$$

where n = ratio of characteristic parameters (air and earth) in the Hertz vectorial function.

d = ratio between height of vertical dipole and wave length radiated.

x = an expression depending on relative magnitude of displacement and conduction current.

The functional relationship is shown graphically in various ways.

Generation and Application of High Tension Direct Current. (H. Grünewald, Z.V.D.I., Vol. 79, No. 46, 16/11/35, p. 1375-1385.) (256 Germany.)

The various methods for generating high tension direct current are described in detail.

Nature provides an example of direct generation in the thunderstorm. Working on similar lines, but with more modest results, are the various types of electrostatic or influence machines. The more usual technical process is the rectification of high tension alternating current. This can be carried out either by means of mechanical circuit breakers, gas valves, or arcs.

As an alternative the high tension alternator can be fitted with special commutators which may be either stationary or rotary. An example of the latter type is the Swedish Glesium process in which its alternating wave form is distorted so as to render longer rest periods of zero current available for the commutator.

A very extended bibliography of 110 references is attached.

Photoradio Apparatus and Operating Technique Improvements. (J. L. Callahan and others, Proc. Inst. Rad. Eng., Vol. 23, No. 12, Dec., 1935, pp. 1441-1482.) (402 U.S.A.)

A brief review of photoradio reception and progress up to 1928 is included in the introductory part of the paper.

Improvements to terminal equipment which make possible greater fidelity of half-tone transmission over long-distance radio circuits are described. Radio circuit distortion is discussed and compensation methods suggested. A mathematical analysis of the photoradio keying is appended.

The Theory of Dauzere on the Conductivity of the Air in Regions likely to be Struck by Lightning. (E. Mathias, Comptes Rendus, Vol. 201, No. 5, 29/7/35, p. 317.) (489 France.)

The danger of a particular spot A being struck by lightning depends on the total conductivity s and the conductivity gradient r of the air in the vicinity. Whilst high values of r and s are essential they do not necessarily lead to A being struck, unless vertical air currents assist the passage of the ions. On account of the greater mobility of the negative ions, equalisation of potential by the motion of such ions is more readily accomplished and is generally less dangerous (St. Elmo's fire). In the case of very severe storms, lightning carried by positive ions will strike the spot emitting the negative ions.

The presence of St. Elmo's fire is not, therefore, an invariable safeguard against being struck by lightning.

Operation of Ultra-High Frequency Vacuum Tubes. (F. B. Llewellyn, Bell Tele. Pub. No. B.890, Oct., 1935.) (620 U.S.A.)

Previous electronics analyses are extended by the introduction of more general boundary conditions. The results are applied to the calculation of the rectifying properties of diodes at very high frequencies and to the amplifying properties of negative grid triodes at both low and high frequencies. The effect of space charge on the various capacitances in triodes is discussed, and formulas for the amplification factor and plate impedence are presented in terms of the tube geometry. Finally, a discussion of the input impedence of negative grid triodes is given together with a comparison of the theoretical value with the results of measurements made by several well-known experimenters.

Earth Potential Measurements during the International Polar Year. (G. C. Southworth, Bell Tele. Pub. No. B.892.) (681 U.S.A.)

Most of the data point toward the generally accepted view that there is a close relation between earth resistivity and the direction and magnitude of earth potentials. However, there are some inconsistencies noted which tend to make this less definite.

A Note on the Source of Interstellar Interference. (K. G. Jansky, Bell Tele. Pub. No. B.897, July, 1935.) (682 U.S.A.)

It is concluded that the source of these radiations is located in the stars themselves or in the interstellar matter distributed throughout the milky way.

Because of the similarity in the sound produced in the receiver head set, it is suggested that these radiations might be due to the thermal agitation of charged particles.

Radio Compass. (L'Aérophile, Vol. 44, No. 2, Feb., 1936, p. 43.) (849 France.)

The principle of the American instrument (B.N.S.) is illustrated with the help of a wiring diagram. Reference is also made to a French compass (Busignies L.M.T.) of greater sensitivity and therefore more suitable for navigation outside the regular channels. Both instruments are direct reading, zero being indicated when the plane heads in the direction of the emitting station.

The "Telefunken" Wireless Direction Finder. (Luftwissen, Vol. 3, No. 2, Feb., 1936, pp. 40-43.) (883 Germany.)

The instrument functions on the well-known principle of heart-shaped response curve when a line and frame aerial are combined. By putting the non-directional area in series with one or other of the branches of the frame the heart-shaped response curve undergoes virtual reflection.

The response is only unaffected if the plan of the frame aerial is perpendicular to the direction of the wireless wave. A small deviation causes, however, considerable differences as the line aerial is switched over. This forms the basis of the instrument, the difference in response being indicated either by ear or eye.

The complete instrument including battery weighs 27 kg.

REVIEWS

Aerodynamic Theory

Edited by W. F. Durand. Published by Julius Springer, Berlin. Price 28 R.M.

This is the last volume of the series of monographs on aerodynamic theory issued under the auspices of the Guggenheim Fund for the Promotion of Aeronautics. It starts with a paper by W. F. Durand in which a general treatment of aeroplane problems is given without the use of mathematics, starting from the assumption that the behaviour of an aeroplane is a complex of four systems, the lifting system, the non-lifting system, the propulsive system, and the control system. The paper will be valued by readers who have difficulty with mathematics.

The second division consists of a paper by Max M. Munk on the Aerodynamics of Airships, followed by two papers by R. Arnstein and W. Klemperer on performance. The first paper contains an excellent summary of the state of theoretical knowledge in regard to airships, while the other two deal with more practical aspects.

There is then a division by E. G. Barrillon, who is Director of the Naval Experimental Tank at Paris, on seaplanes and flying boats, which is concerned mainly with hulls from the theoretical and practical standpoint. The method of treatment of these problems has not, as far as I know, been previously published in English and is of considerable interest. This is followed by a paper by H. L. Drydon on the Aerodynamics of Cooling, in which the existing knowledge on this subject is treated mathematically. It is an excellent treatise on this matter.

As this is the last volume of the series the opportunity is taken to thank the Guggenheim Fund for the very real service it has done to aeronautics by the issue of this publication. As a consequence there is now available in concise form a statement of modern knowledge of this subject so arranged, indexed, and set out, that it can be easily and quickly referred to. In all cases the authors selected are authorities on the subjects with which they deal, and the complete work is invaluable as a source of aeronautical information.

The Pilots' Book of Everest

By Squadron Leader Lord Clydesdale and Flight Lieut. D. F. M'Intyre. Published by William Hodge and Co., Ltd. Price 10s. 6d.

The conquest of Mount Everest by the aeroplane was a notable feat. That it had been possible to fly over the top of this formidable mountain and to take photographs which have increased enormously geological knowledge of the neighbourhood was a fact that struck the public imagination; especially as it was all over in a few short weeks while the ground parties had been struggling unsuccessfully for years.

The pilots' accounts of expeditions of this type are always interesting. It is they who carry out the climax, who risk their lives on the thoroughness of the preparations, and who, if anything goes wrong must have to do the best repairs they can in a cramped cockpit, in heavy clothing and gloves, in intense cold and sometimes under the handicap of a shortage of oxygen.

There is no doubt that the staff work was excellent in spite of the very short time available for preparation. There was certainly a case of a survey camera refusing to work, and the oxygen apparatus always seemed to be on the

point of breakdown, but this could hardly be helped as the apparatus was undoubtedly the best of its kind available. Oxygen was essential at the heights flown, and even when it was supplied, even in ample quantity, it was found that there is a decrease in normal mental efficiency, a fact which is worth consideration by those interested in high altitude bombing.

The account should be read by all interested in flying. Not only is it of historical importance but it contains experiences which would be invaluable to future expeditions. Add to this that it is well written, well illustrated, and that it contains an account of an adventurous and pioneering flight which was completely successful.

Let us not forget that it was Lady Houston who made the thing possible. Without the money that she gave to the expedition it would have been impossible that it could ever have started, and those magnificent photographs which so many of us have seen would have been a dream of the future.

CORRESPONDENCE

Retractable Undercarriages

Too late for insertion in the discussion on the above paper last month, the following communication has been received from Mr. A. E. Raymond, Chief Engineer of the Douglas Aircraft Co. Inc., Santa Monica, Calif. In view of several requests for detailed weight and strength data on retractable undercarriages, it is felt that Mr. Raymond's remarks and figures will be appreciated by designers in this country. Mr. Raymond writes as follows:—

Mr. Dowty's article on Retractable Undercarriages is the most complete that I have yet seen. In response to request for information on the Douglas " DC-2 " transport, I have pleasure in giving the component weights and the design conditions for the " DC-2 " landing gear. It will be noted that the figure of 5 per cent. of the gross weight, as stated in the paper, was a fairly close approximation.

As an answer to the usual arguments of additional weight and maintenance problems presented by the retractable gear when compared with the fixed external gear, I would like to call the airplane designers' attention to the superior maintenance possible due to the lack of fairings on the retractable gear, which not only render inspection of the structure more difficult, but are themselves liable to damage and clogging with dirt; and to the weight advantage not often recognised, in the saving in fuel for the same distance run, due to the higher speed at the same engine power.

For a 1,000-mile run, the Douglas transport uses 912lb. less fuel at cruising power with the gear retracted than with it extended. Even considering this figure halved for a well faired external gear there still remains 456lb. which must be subtracted from the weight of a retractable gear to obtain a true comparison with a fixed gear. The weight of the " DC-2 " gear is 917lb., including the retracting struts, or 4.94 per cent. of the gross weight of the ship. Adding 60lb., which is half of the weight of the hydraulic system which operates both the landing gear and wing flaps, and subtracting the 456lb. of fuel saved, we find that the weight of a conventional landing gear would have to be 521lb., or 2.8 per cent. of the gross weight for the same take-off weight for a 1,000-mile run.

I agree with Mr. Dowty that a hydraulic retracting system is superior to a mechanical one, but in connection with his suggested 60 seconds retraction and

30 seconds extension, I would like to mention that most recent American designs have provided for not greater than 15 seconds operating time. The latest Douglas retracts its landing gear in eight and extends it in five seconds. In a bi-motor airplane a high speed of retraction is essential as it increases climb in the period just after take-off, a very important point in the event of failure of one engine.

DOUGLAS " DC-2 " TRANSPORT.

LANDING GEAR WEIGHTS.

Item.	Weight (lb.)	
Wheels and brakes	188	
Tyres and tubes	226	
Axles	35	
Shock-absorber struts	205	
Rear brace struts	83	
Upper trusses	108	
Retracting struts	28	
Mechanical locks	12	
Brake operating mechanism	32	
Total: Landing gear	917	(4.94%)
Total: Hydraulic operating system (landing gear and wing flaps)	120	(0.65%)

Notes.—Percentage ratios are based on a gross weight of 18,560lb. for the complete airplane.

Assuming landing gear retraction system equals half of total hydraulic system (*i.e.*, 60lb.), then complete retractable landing gear weighs 977lb. (5.3 per cent. of gross weight).

LANDING GEAR.

DESIGN LOAD FACTORS.

(Based on ultimate strength of materials.)

Condition.	Load factor.	
Level landing: Thrust line horizontal	Vert.: 4.86	
	Drag: 1.21	
Three-point landing: Landing gear and tail wheel	Vert.: 4.86	
Ground loop: Three-point attitude with zero load on tail wheel	Vert.: 1.00	(per wheel)
	Drag: 0.55	,,
	Inward: 1.00	,,
Braked landing: Three-point attitude with zero load on tail wheel	Vert.: 2.00	
	Drag: 1.10	

The 603rd Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Society was held in the Lecture Hall of the Institution of Electrical Engineers at Savoy Place, Victoria Embankment, London, W.C.2, on Monday, February 3rd, 1936. In the chair: The President (Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P.). A paper on "Airscrew Development" was presented by Dr. H. C. Watts.

The PRESIDENT: Dr. Watts had been a Fellow of the Society since 1917; he was the Technical Director of the Airscrew Co., Ltd., and an expert on airscrews and allied problems. In July, 1920, he had contributed to the Society's Journal an article, entitled "A Note on the Theories of Screw Propulsion." But he had made no other contributions, and no doubt, added the President, it was with a bad conscience that he came to deliver his first lecture on a subject with regard to which he was so distinguished.

AIRSCREW DEVELOPMENT

By H. C. WATTS, M.B.E., D.Sc., M.Inst.C.E., F.R.Ae.S.

Airscrew development has proceeded along four main lines:—

(1) Aerodynamic design.
(2) Materials.
(3) Adaptation to engine and aircraft.
(4) Fans for cooling and ventilating purposes.

Section (4) I have omitted. It may form the subject of a paper elsewhere. Section (1) I have barely outlined. It is of great interest, but I have concentrated on Sections (2) and (3) as being of immediate practical concern.

(1) AERODYNAMIC DESIGN.

It was in 1892 that M. Drzewiecki hinted in a paper presented to L'Academie des Science (1) at the present basic method of airscrew design and at about the same time Lanchester independently suggested the same idea in this country.

The method consisted of dividing the blade into a number of strips, considering each such strip as an elementary aerofoil moving with a velocity the resultant of the forward and tangential velocities, giving the strip an angle of incidence to this resultant direction and then, from a knowledge derived from wind tunnel experiments of the lift and drag forces, estimating the elements of torque and thrust and, finally by integration, the power absorbed and the efficiency of the airscrew.

This was followed in 1916 by the addition of the Momentum Theory. The earlier theory implicitly assumed that all the momentum velocity from which the thrust resulted was imparted to the air behind the plane of rotation. This combined theory resulted in the assumption of one half the momentum velocity as taking place in front of the airscrew.

The use of wind tunnel aerofoil data, however, was inconsistent with such a theory. In the wind tunnel the aerofoil was already subjected to an "inflow." By using wind tunnel aerofoil data it was contended this inflow was thus implicitly taken into account. The inflow to be added to the axial velocity of the

early simple theory was only that due to blade interference. Accordingly, as the result of Fage's work (2) at the N.P.L., the inflow factor was changed from Froude's one-half to Fage's one-third, and this figure occurs both in Bairstow's Applied Aerodynamics and my own work, both published in 1920.

It was left to Glauert to clean up the rather empirical state into which airscrew theory had by that time developed. His contribution, known as the Vortex Theory, will be found in his own work (3) and in R. and M. 786 (4). Put briefly, he reinstated the inflow factor of one-half and added the correction of the aerofoil data for infinite aspect ratio.

By this time the National Physical Laboratory had carried out a series of tests (5) on a family of airscrews having a varying number of blades, varying solidity ratios and varying pitches. Thrust and torque coefficients calculated (6) by Glauert's Vortex Theory gave remarkably close agreement with the results of these tests. The family of airscrews has recently been repeated (7) and extended with greater care and improved apparatus, and the results confirm even more closely the accuracy of Glauert's work, to which has now been added the last refinement of Goldstein's tip correction (8).

Thus airscrew theory now stands well checked by model tests, available for whatever further aerodynamic developments may arise. Every designer has, however, his own quick methods of using these theories in practical design, usually based on the performance of a section situate at 0.7 or 0.75 of the tip radius. An excellent method is given by C. H. N. Lock (9).

(2) MATERIALS.

Wood.—In this country wood has remained the material used for the majority of airscrews for all powers and sizes. This position is not one of conservatism. On the score of cheapness and lightness it has no near rival. Below a diameter of 8 feet and for high tip speeds it loses efficiency relative to the metal blade, not so much because of its relatively thick sections, but because in small sizes the minimum practical radius of the metal sheathed leading edge is relatively large compared with the maximum thickness and blade width, and the sections are relatively poor aerofoils. Above 8 feet and at high tip speeds the wooden airscrew must also concede an advantage to the metal screw for maximum flying speed on account of its thicker blade sections, but for the same reason it can claim an improvement for take-off and climb because of the higher lifts and lesser tendency to stall. Whatever efficiency the larger types of wooden airscrews may lose they frequently more than regain, because their material and construction are such that they can be so exactly designed and made to suit the required specification and their cheapness permits of trying out if necessary a number of alternative designs so that the very best possible result is finally attained. The designer of the metal airscrew, particularly of the detachable blade variety, often fails to realise the best result because of the commercial necessity of using a very limited number of standard forgings.

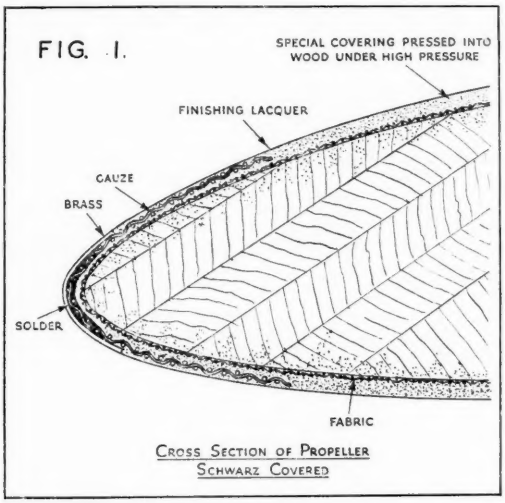
The outstanding advantage of wood is its safety and its freedom from fatigue. It is a natural absorber of the energy of vibration, and therefore an ideal material for use on an internal combustion engine with its periodic torque variations.

Wood has, however, two grave disadvantages. It absorbs and gives up moisture, with resulting distortion, and it is not hard enough to resist erosion. Both these points have to some extent been overcome by various protective finishes and by metal sheathing the leading edges. The metal sheathing is put on in segments to avoid the danger of fracture due to fatigue. So protected, the life of an airscrew on aircraft in regular flying services—such as our chief commercial air lines—is in many cases over 3,000 hours, but for seaplane work, however, the standard method of metal sheathing has never been wholly satisfactory.

Both disadvantages have been overcome by the Schwarz process of protection. This consists in completely covering the airscrew with a film of cellulose acetate

about one millimetre thick. Fig. 1 shows a diagram of the construction. The leading edge is covered with a thin strip of cellulose material. Over this and the whole of the blade and boss is a layer of fabric or high tensile steel gauze according to the duty required from the airscrew. The leading edge is covered with a strip of specially woven phosphor bronze wire gauze, to which is sweated a nosepiece of brass. The airscrew after being thus prepared is covered with a sheet of cellulose material, which is applied in a soft and plastic condition. The necessary adhesion to the wood is obtained by placing the airscrew, whilst its covering is still plastic, in a specially designed autoclave and submitting it at normal temperature to a pressure of several atmospheres, varying according to the timber used.

Examination of a section of an airscrew so covered reveals that the covering has been forced right through the fabric and wire gauze into the pores of the



wood, and can only be removed by tearing away the wood with the covering. The resultant surface can be highly polished, and there is no break in its continuity as with the older forms of sheathing. This perfectly smooth and uninterrupted surface results in low profile drag, with corresponding increase in efficiency, particularly at high tip speeds. The covering is so hard and yet so elastic that it is impossible to stamp it with steel dies. All identification particulars are stamped on a metal plate let into the covering at a convenient place on the boss.

The finish serves three vital purposes. It seals the wood and prevents the rapid exchange of moisture with the surrounding atmosphere. It is as resistant as metal to erosion and abrasion, and superior by being non-corrosive. Fig. 2 shows a 24ft. diameter Schwarz covered wooden airscrew fan, which has now been working continuously day and night for eight months in a water-cooling tower, in an atmosphere of chemical fumes and the equivalent of continuous rain.

The torsional rigidity of the blades is increased by the covering, thus making it possible to use thin sections when and where desirable. Such is the standard finish for all wooden airscrews in the Royal Air Force, and its use is spreading on civil aircraft.

Another serious disadvantage of wood is its low shearing strength. This weakness in shear has hitherto prevented the use of wood for detachable blades

necessary for variable pitch airscrews. I am in a position to-night to say that by an extension of the Schwarz process this defect has been overcome.

The wood at the root of the blade is impregnated and compressed. This compressed root is machined to the usual cylindrical form and screwed into a steel sleeve. Further impregnation under high pressure serves completely to close up any clearance left in fitting the sleeve. The blade can be fitted with a fixed pitch into the usual type of hub or fitted with ball bearings and used in variable pitch hubs. The compression of the root is permanent. Daily measure-

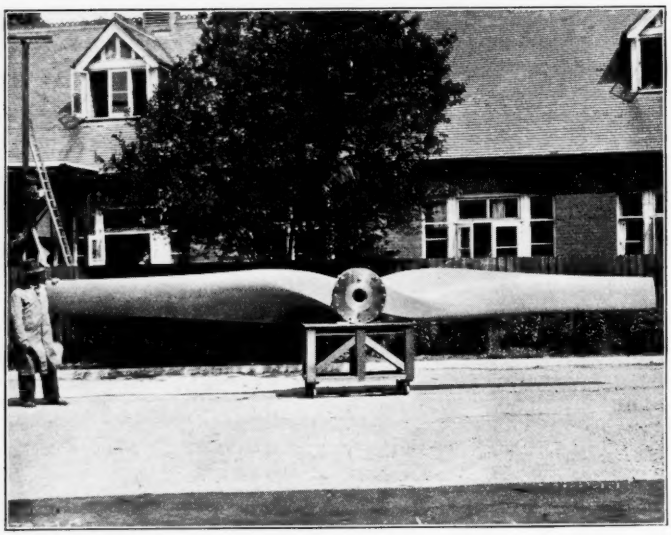


FIG. 2.

ments taken at constant normal temperature of a cube of the compressed material show no perceptible variation. The specific gravity is about 1.4, and the ultimate tensile strength 14 to 15 tons per sq. in. Other mechanical properties are given in the Appendix. The weight compares favourably with the weight of metal blades, even in magnesium alloy, and I do not think the limit of weight to which these blades may be reduced has yet been reached. Only the inner end of the blade is treated and compressed. The main portion of the blade has a specific gravity of 0.5 or less. The inertia loads, including the direct centrifugal pull on the hub, is less than one-half of the loads from any equivalent metal blade, even of the same weight. Added to its lightness and very low inertia forces, it has the advantage of no limitation in size. A 25ft. blade for a 50ft. airscrew is practical if required.

Metal: Aluminium Alloy.—The first successful departure from wood was the Reed airscrew, made of aluminium alloy. The sections are thin and therefore the blade is sufficiently flexible to set itself closely along the direction of the resultant forces, thus reducing the bending moment. This flexibility has also its drawbacks. Unless the material is perfectly homogeneous and the blades of exactly the same dimensions the deflections are unequal. This sets up unbalanced moments and consequent vibration, leading to the necessity of special dynamic balancing.

Thin sections give an advantage for maximum speed, but tend to lose thrust at low speeds because of lower maximum lift and earlier stalling. The logical

development would be to use an equally thin section with its centre line cambered, thus obtaining high maximum lift and late stalling, combined with low profile drag. This, however, would seriously complicate manufacture and destroy the very flexibility which is the essential nature of the Reed airscrew, and I presume these are the reasons why such development has not taken place.

Following closely on the Reed airscrew came the metal blade, adjustable for pitch in a central hub, the type which rapidly became standard in America. The detachable blade lends itself to mass production. For any given diameter it is possible to stock a single type of blade and to obtain two-, three- or four-bladed airscrews of any desired pitch by suitably setting the required number of blades in a suitable hub.

As in the Reed, this airscrew has thin sections from which the blade has to merge into a rigid cylindrical root, and care must be taken in design to see that this merging is not too sudden. The true aerofoil does not start until well out into the blade, and this results in poor cooling for engines which have been used to relying on the airscrew slipstream. In America, cooling is left to the engine designer and the shape of the inner portion of the blade decided purely on the basis of uniform stress distribution.

The weakness of this blade is the danger of catastrophic failure due to fatigue. The danger is fully appreciated in America, as shown by the general maintenance instructions from which is extracted the following summary:—

> In the hands of first-class airlines, airscrews have been found free from signs of fatigue after 2,500 hours. In other hands, fatigue cracks have been found in very much less time.
>
> Rigid maintenance and close co-operation between user and manufacturer is essential to reduce the danger of failure to small proportions. Hub and blades should be inspected daily; hubs searched for fatigue cracks and blades for dents, nicks, erosion, pitting, etc. These are sources of danger and should be removed at once. Notches in the leading and trailing edges are especially dangerous. Only by such careful treatment can blades be maintained in safe condition between overhauls. Overhauls should take place at least every 200 hours. For this purpose propellers should be returned to the makers. Here the propeller is dismantled. The hubs are searched for fatigue cracks with a De Forest Magna Flux machine. The blades are cleaned and etched all over to facilitate search for cracks. Any suspected crack is further etched locally for better inspection. The instructions state that every transverse mark must usually be taken as a warning of incipient failure and the blade scrapped.

Theodorsen, in a paper last March to the Institute of Aeronautical Sciences, refers to the recent increase in the number of propeller failures and describes the intensive research which is going on in the U.S.A. on the whole question of propeller vibration, with a view to reducing fatigue failure to small proportions.

The remaining drawback of aluminium alloy is weight—a drawback which becomes greater as sizes increase, and this has led to the development of the use of magnesium alloys.

Magnesium.—Magnesium alloys have a specific gravity of 1.8, as compared with 2.8 for aluminium alloys, and about the same weight-strength ratio. At first sight one might expect therefore a 30 per cent. saving on weight. Airscrew blades, however, are limited in minimum thickness by considerations of flutter which depend on the modulus of rigidity of the material used. Taking this factor into account leaves a weight saving possibility of 15 rather than 30 per cent.

Magnesium is now being extracted from its carbonates, of which plentiful supplies exist in this country. These two features—weight saving and a non-imported supply of raw material—are forcing the development of the magnesium blade. In this country it is still in its experimental stages, and experience has been somewhat conflicting. Some blades have failed in use and others have given

satisfactory results over considerable periods of flying. It is, however, hoped to obtain better and more uniform strength throughout the blade by changes in the alloy composition and by improved forging technique.

In the appendix are given the chemical and physical properties of the latest alloy used for extruded blades in this country and for the German AZM alloy.

Two methods of manufacturing the blade blanks are in use—one consists of extruding the round bar, pressing the rough dummy shape using Fuller tools and finally pressing the complete blade in a die; the other method, known as the Mitchell system, is extrusion of the blade to shape from the cast ingot. Tests to date rather indicate that the latter method is superior to the method used in Germany.

Magnesium alloys are even more sensitive than aluminium alloys to stress concentration around changes of section. Therefore it is perhaps significant that with their knowledge and experience of metal airscrews, the magnesium blade is being developed much more slowly in America than in Europe.

The material corrodes easily and must be suitably protected. The chromate treatment is partially effective as a preventative, but the film is easily damaged and cannot be maintained along the leading edge. Rubbing down with lanoline after each flight is necessary.

Hollow Steel.—The weight of solid metal airscrews has from time to time led to the consideration of the possibilities of hollow steel blade. It was hoped that a hollow blade would give considerable weight saving and in large sizes might even approximate to the weight of wooden screws. There is in the appendix a brief description of the work done on hollow steel blades in this country. It is sufficient to say here that the blades manufactured by Messrs. Metal Propellers, at Croydon, came only just short of success. The many problems connected with practical production were solved. Accurate blades were produced in quantities, and their weight compared advantageously with that of their solid rivals. They sustained exhaustive spinning tests, engine bench tests and development flight trials, and yet put into service they failed from fatigue in less than 100 flying hours. The fractures occurred in two characteristic places. The one on the root just outside the sleeve, and the other on the pressure face on the outer single lamination. Contrary to general anticipation, least trouble was experienced on the welded leading and trailing edges.

I understand that later experience in developing the same type of airscrew in America is revealing not only the same type of fractures, but the same characteristic positions, although chrome-molybdenum steel has been used in place of the ordinary mild steel used in this country.

Both of these types of failure may possibly be surmounted by the use of a higher quality steel and by increased thickness of material, but I can only give it to you as my personal opinion, after ten years' work on this problem, that when the hollow steel airscrew was brought to a satisfactory state of reliability it would be at least as heavy as the solid aluminium alloy airscrew.

Micarta.—Micarta is a trade name for a material made up of superimposed layers of fabric impregnated with synthetic resin. For resistance to fatigue it ranks as an equal with wood, and this is the main reason for efforts to develop this material for airscrews. In addition it was expected that some saving in weight might be effected as compared with metal. It has, however, a low torsional and flexural stiffness, and to avoid flutter the blade must have approximately the same relative thickness as in wood. Thus experimental airscrews have proved to be comparable in weight with metal airscrews.

For the hub and inner parts of the blades to be of reasonable proportions, it is necessary to load the material up to about 3,000lbs. per sq. in.—a figure higher than the limit of proportionality. Under such a stress the material creeps, recovering only slowly from the strain after the load is removed. There is thus risk of blade deformation with loss of balance and interchangeability. Endurance

flight tests are being made to determine how low this material must be stressed to avoid trouble due to creep.

Micarta airscrews in small quantities have been made since 1918, and they have been used on some outstanding long-distance flights, but I am not hopeful that micarta or other plastic materials will have wide application as a material for airscrews until considerably more research has been carried out. At the moment its field must be limited to lightly-stressed blades, and even were it

TABLE I.

PROPERTIES

Specific Gravity	Mass Ultimate Strength Ratio	Mass Fatigue Strength Ratio	Internal Damping	Resistance to Abrasion.	Resistance to Weathering.
Wood	Wood	Wood.	Micarta	Steel	Micarta.
Sch. Wood.	Sch. Wood.	Sch. Wood.	Wood.	Sch. Wood.	Sch Wood.
Micarta.	Mag. All.	Mag. All.	Sch Wood	Alum. All.	Alum. All.
Mag. All.	Alum. All.	Micarta.	Mag All.	Mag. All.	Steel.
Alum. All.	Steel.	Alum. All.	Alum All.	Micarta.	Mag. All.
Steel.	Micarta	Steel.	Steel.	Wood	Wood.

TABLE II.

ADVANTAGES

Noise	Weight.	Safety & Depend-ability	Efficiency	Repair-ability	Wear.	Possibility of Larger Sizes.	Ease of Manufac-ture.	Availability of Material.
Micarta	Wood	Sch Wood	Alum All.	Alum All	Steel.	Wood.	Wood	Mag. All.
Steel	Sch Wood	Wood.	Mag. All.	Mag. All.	Sch. Wood	Sch. Wood	Sch Wood	Steel.
Sch Wood	Mag. All	Alum All	Sch. Wood	Wood.	Alum All	Micarta	Mag. All.	Sch. Wood.
Wood	Micarta.	Mag. All.	Wood.	Sch Wood	Micarta.	Steel.	Alum All.	Wood
Mag. All.	Steel.	Micarta	Micarta	Micarta	Mag All.	Alum. All.	Micarta.	Alum All.
Alum. All	Alum. All	Steel	Steel.	Steel.	Wood	Mag All.	Steel.	Micarta.

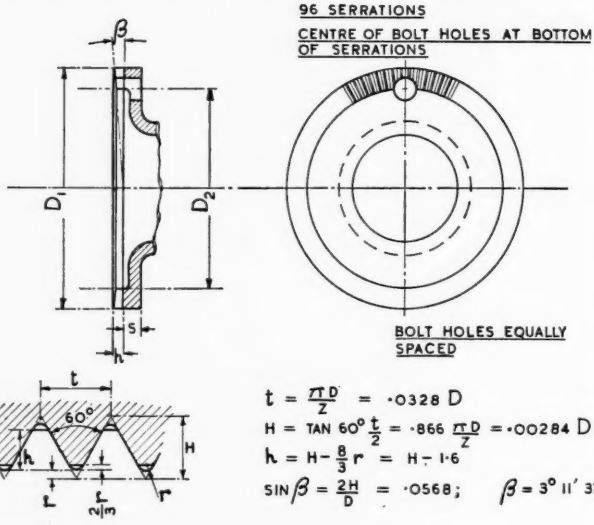
developed to be suitable on all other grounds the necessity of heated dies makes it commercial only for large production in one type (see appendix for mechanical properties).

I have prepared Tables I and II to show my opinion of the relative merits of the various materials at their present stage of development. These qualities and advantages are placed under the same headings, with some additions, as used by Caldwell in his paper in the S.A.E. Journal, September, 1934. Apart from the fact that I have added Schwarz covered wood as a separate " material," the order of merit differs little from his. The chief differences are that under

dependability he gives wood the third place after aluminium alloy and micarta, whilst I give wood an easy first and under repairability I have placed wood below the light alloys, yet I add the remark that though its order of repairability is low, the cost of replacing is probably less than the cost of repair of the other types.

As a connecting link between this section and the next, I should like to refer to a factor which has had a serious effect on the non-development of the

GERMAN AIRSCREW FLANGE DIMENSIONS



$t = \frac{\pi D}{Z} = \cdot 0328\ D$

$H = \tan 60° \frac{t}{2} = \cdot 866 \frac{\pi D}{Z} = \cdot 00284\ D$

$h = H - \frac{8}{3} r = H - 1 \cdot 6$

$\sin \beta = \frac{2H}{D} = \cdot 0568; \quad \beta = 3° 11' 37''$

ALL DIMENSIONS ARE GIVEN IN MILLIMETRES

DIAM^R D_1	P.C.D. D_2	DIAM. OF BOLT HOLES, d.	DEPTH OF SERRATION, h.	FLANGE THICKNESS, S	BOLTS NO. OFF	BOLTS THREAD	H.P. / N
100	80	10·5	1·2	8	6	10 X 1	·04
(110)	90	10·5	1·5	8·5	6	10 X 1	·07
120	100	13	1·8	9	6	12 X 1·5	·12
(135)	112	13	2·2	9·5	6	12 X 1·5	·19
150	125	13	2·7	10	8	12 X 1·5	·27
(165)	140	13	3·1	11	8	12 X 1·5	·44
185	160	15	3·7	12	8	14 X 1·5	·62
(205)	180	15	4·2	13	8	14 X 1·5	·82
230	200	17	4·9	14	8	16 X 1·5	1·10

THESE FIGURES GIVEN ONLY FOR GUIDANCE.

BRACKETED SIZES SHOULD BE AVOIDED.

detachable blade airscrew in this country. That is our persistent refusal to standardise airscrew shafts.

Such standardisation has taken place in France, Germany and the U.S.A.

I have impressed on all concerned over the last ten years that the detachable blade airscrew and its logical successor, the variable pitch screw, would be greatly handicapped until shaft standardisation was accepted by or forced on the engine industry. For anyone setting out to supply detachable blade

airscrews for various types of engines it was a severe commercial handicap, particularly in the early days of experimentation, to have to produce various standard hubs to suit the different shafts in use in this country. The necessity of variable pitch is, I understand, at last forcing what should have been done ten years ago.

Shaft standardisation has taken three forms. The cone and key shaft in France, the parallel splined shaft in America, and the flanged end in Germany. I fully admit that premature standardisation may in itself handicap development. The type of shaft standardised may suit one particular type of screw in favour at the moment of standardisation, but it may be a serious handicap to some more promising later invention. For this reason I prefer the German flange. It leaves the field open for both existing designs and future development. The airscrew designer can fit direct to this flange, omitting the central shaft and saving considerable weight, or he may fix to it whatever type of shaft best suits his particular design.

Particulars of the German standard flanges are given in the appendix. Details of the American standard shafts are to be found in " The Handbook of Aeronautics," and a set of standard flanges has been drawn up and issued in this country in the B.S.I. Report No. 87, Part 2.

(3) Adaptation to Engine and Aircraft.

There has recently been published a report (7) on tests on a family of airscrews of various pitches ranging from 0.3 to 2.5 diameters. This report is a revision as well as an extension of report R. and M. 829 (5). I have extracted the torque characteristics of the various airscrews tested, and shown them with superimposed equal efficiency lines in Fig. 3.

In general, the point corresponding to maximum flying speed with full throttle will be somewhat below maximum possible efficiency as shown by point A for a pitch of 1.5D. This point corresponds to the design conditions.

The torque of an internal combustion engine is approximately constant with rate of rotation, and for the purpose of this paper I shall assume it so. The resistance torque of the airscrew, however, varies as the square of the rate of rotation and is expressed at $\rho k_q N^2 D^5$, where ρ is density of the air, N is the rate of rotation, D the diameter of the airscrew, and k_q is the coefficient shown in Fig. 3 varying with v/nD and pitch-diameter ratio.

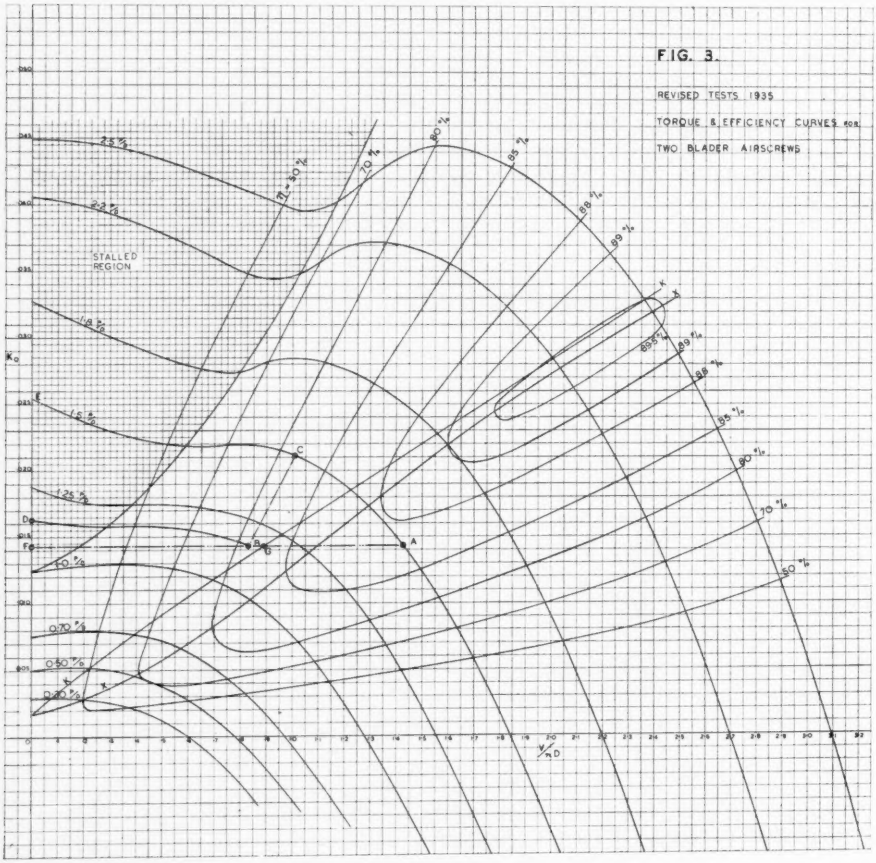
For a fixed pitch airscrew the torque coefficient increases as the aircraft speed decreases. The rate of rotation must therefore fall so that the airscrew resistance torque $\rho k_q N^2 D^5$ remains equal to the constant engine torque. The rate of rotation is thus a minimum at low aircraft speeds just when unfortunately the maximum power is wanted for take-off.

Fig. 4, derived from Fig. 3, shows for two airscrews having fixed pitches of 0.7 and 1.5 diameters the change in rate of rotation and thrust as the aircraft speed alters. In this figure, as in all subsequent figures, the thrust t, the speed v, and rate of rotation n, are expressed in terms of the designed thrust T, the designed speed V, and the designed rate of rotation N.

It will be noted that although the revolutions fall for the airscrew with $0.7D$ pitch, the thrust steadily rises to a maximum at static conditions. For the airscrew with $1.5D$ pitch the thrust at first rises and then falls away to a value little greater than at top speed. This fall is due to the stalling of the airscrew blades—a phenomena identical with the stalling of a wing. The figure clearly shows the drawbacks of the fixed pitch airscrew—firstly a decrease of revolutions with loss of power, and secondly and much more important a loss of thrust on the higher pitch airscrew due to the blade stalling. This leads direct to the main theme of this paper: How to develop the airscrew to avoid these losses and to maintain at all speeds the maximum possible thrust.

Look again at Fig. 3. One would like the airscrew to work at maximum possible efficiency at all speeds. To achieve such a result, the torque coefficient

curve of such an ideal airscrew must be that represented by line X.X.* since at any value of v/nD this line corresponds to maximum efficiency. It is cutting across the torque curves of various pitches. Hence the conclusion that the first step towards the achievement of our ideal is some arrangement whereby the pitch of the blade can be changed with changing speed. Further, in addition to aiming at maximum efficiency, one would like also maximum power and hence maximum constant engine revolution at all speeds. This means that the power absorbed by the airscrew, proportional to $\rho k_q N^3 D^5$, must remain constant. The



torque coefficient k_q for the ideal airscrew is, however, decreasing with falling speed. Hence the second conclusion that one of two things must be arranged for, either the diameter or the airscrew revolutions must be made to increase. If the diameter is kept constant the airscrew revolutions must increase. If the airscrew revolutions are kept constant the diameter must increase. The first alternative means variable pitch plus a variable gear. The second alternative means variable pitch plus variable linear dimensions.

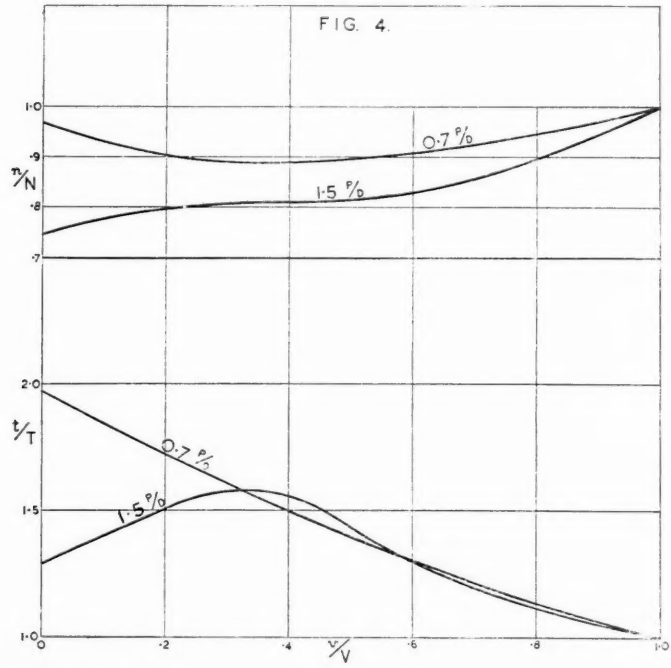
The second alternative I dismiss. It means adding all the complications of variable diameter to those of variable pitch.

* For a qualification of this statement, see Appendix.

The first alternative is more practical. Carried to the limit it would involve excessively high rates of rotation in the static condition, but out of it arises a number of possible and practical compromises.

Fig. 5 shows the thrust which would be given by such ideal airscrews having primary pitches of 0.7*D* and 1.5*D* diameter respectively. The figure also shows the thrust for the ordinary fixed pitch gear airscrew. The margin between them represents the field for airscrew development.

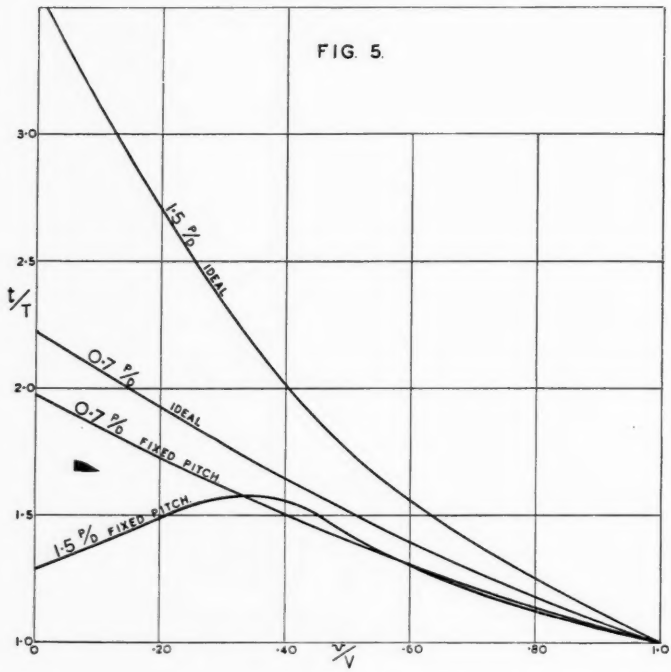
Particularly note that the ideal airscrew increases the static thrust of the 0.7*D* pitch only 13 per cent. It increases the static thrust of the 1.5 pitch 275 per cent. An 0.7*D* pitch airscrew would, generally speaking, be fitted to aircraft having a top speed of 110 m.p.h. The 1.5*D* pitch to an aircraft of 250 m.p.h.



Herein lies not only the reasons and justifications for variable pitch, but also the explanation for its late arrival. In the days of aircraft having airscrews with pitches less than their diameter which, roughly speaking, means speeds of less than 150 m.p.h., variable pitch was not worth while. Not until aircraft of greater speed came into production was there sufficient incentive to attract the necessary capital for the development of V.P. airscrews. I think you will agree that an increase in static thrust of 13 per cent. would not have justified the increased weight, cost and complications. When speeds increased over this "no man's land" lying in the region of 150 m.p.h. the situation completely altered, and the conditions necessary to justify V.P. airscrews arose. As I have already shown, and as I shall emphasise more fully as I proceed, the consideration which so completely altered the outlook was blade stalling. The conventional idea that the object of variable pitch variable gear is to maintain constant engine r.p.m. is not sound. The real vital object is to prevent blade stalling. Any device which does not do this fails to justify itself.

I have indicated an ideal airscrew. I want now to examine a number of more or less practical devices and to see how closely they approach this ideal. I hope to show that with some of them the ideal can be nearly realised.

(i) Two pitches—fixed gear.
(ii) Variable pitch—fixed gear.
(iii) Fixed pitch—variable gear.
(iv) Fixed pitch—two-speed gear.
(v) Two pitches—two-speed gear.
(vi) Variable pitch—two-speed gear.



For each combination I propose to confine myself to three airscrews with primary pitches 0.7, 1.5 and 2.5 diameters. These in practice correspond roughly to speeds of 110, 250 and 450 m.p.h. respectively, and two types of engine are considered:—

(*a*) Non-supercharged.
(*b*) Supercharged to maintain constant power up to, say, 20,000ft.

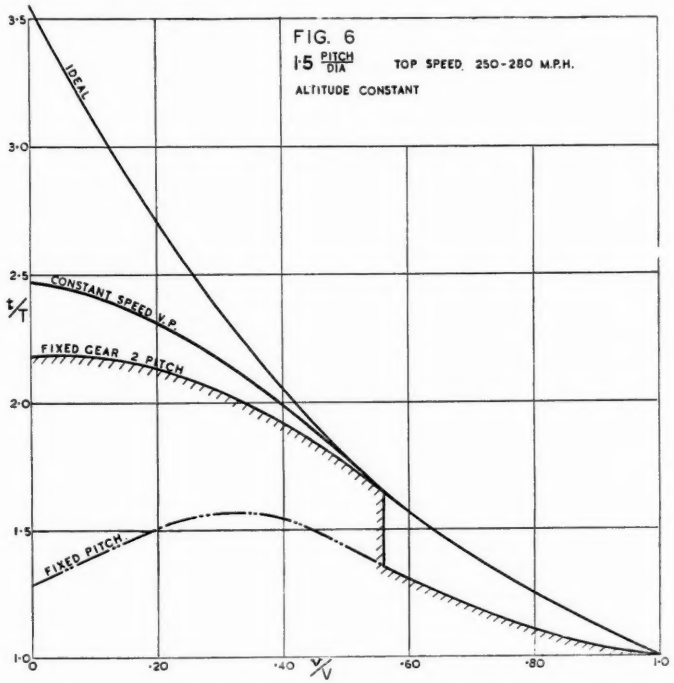
(*a*) Non-Supercharged Engine.

(*i*) *Two Pitches—Fixed Gear, and* (*ii*) *Constant Speed Variable Pitch and Fixed Gear.*

The first case is well exemplified in the Hamilton two-pitch controllable airscrew. This device is a hydraulically-operated mechanism. Oil pressure plus the natural twisting moment moves the blade into its low pitch position. The blades are fitted with counterweights, and when the oil pressure is released the centrifugal turning moment on these counterweights is such that it overcomes the natural turning moment on the blades and forces them into high pitch setting.

This method of operation has the advantage that oil pressure, with the possible troubles due to leakage, is only used for the relatively shorter period of flight in the low pitch setting.

The second case is illustrated by the Curtiss Wright. In principle, this is simple yet effective. The blades are rotated to any required angle, even negative angles, by a 36,000 to 1 gearing driven by a $\frac{1}{4}$h.p. electric motor. In both the above types the pitch is set at the will of the pilot—in the case of the Hamilton to one of two pitches, and in the case of the Curtiss to any desired position. For both types automatic constant speed devices are being developed.

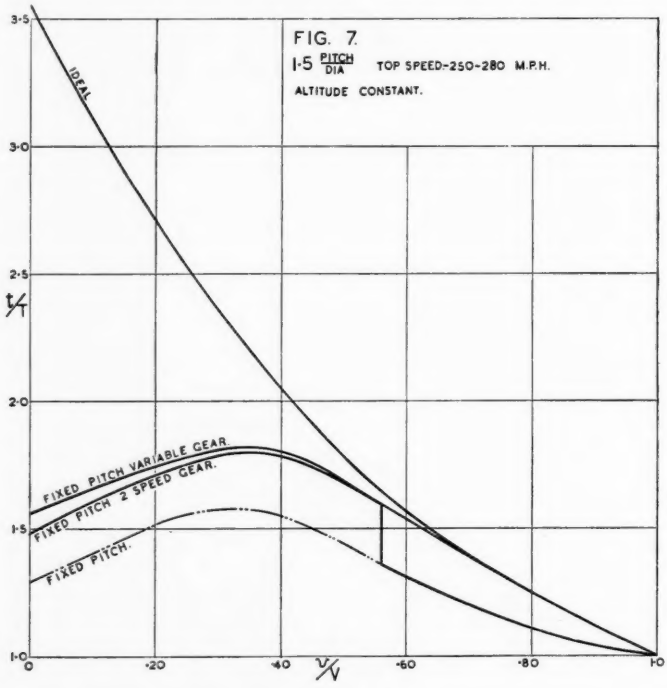


If I do not show or even briefly describe the Hele-Shaw Beacham variable pitch airscrew, it is only because it has already been fully described in a paper to this Society by Dr. Hele Shaw in 1928. It is of the constant speed type, yet controllable in that the pilot can set it to run at any predetermined constant rate of rotation. Like the Hamilton, it operates between a minimum and a maximum pitch, whilst the Curtiss Wright can be set at any angle in the 360° range, a feature with certain obvious advantages.

Having briefly referred to the actual mechanisms, let us examine the effect of the change of pitch in terms of thrust and aircraft speed. For purpose of illustration, I am assuming an airscrew having a primary pitch of 1.5 diameters corresponding roughly to a speed of 250 to 280 m.p.h. Note on Fig. 3 how the airscrews are working. A. represents the designed conditions. The fixed pitch screw works along a torque curve from A. to E. At low speeds it is working in the stalled region. The two-pitch works in high pitch along a torque curve from A. to C. At C., which corresponds to a climbing speed between 0.55 and 0.6 of the level speed, the pitch is changed and the airscrew continues to work from climbing speed to static conditions along a torque curve shown by B.D.

You will note that in the static condition the change of pitch has not brought the screw out of the stalled region. The constant speed screw works along a constant torque curve A.B.F. but just fails to avoid stalling. The ideal airscrew works along the torque curve shown as A.G.K. completely clear of stalling.

Fig. 6 shows the resulting thrusts. Both the two-pitch and the constant speed airscrews fall short of the ideal, but are marked improvements on the fixed pitch. Note the fall of thrust with the two-pitch, due to entering the stalled region near static conditions. The static thrusts are 1.29 for the fixed pitch, 2.18 for the two-pitch, 2.47 for the constant speeds, compared with 3.54 for the ideal.



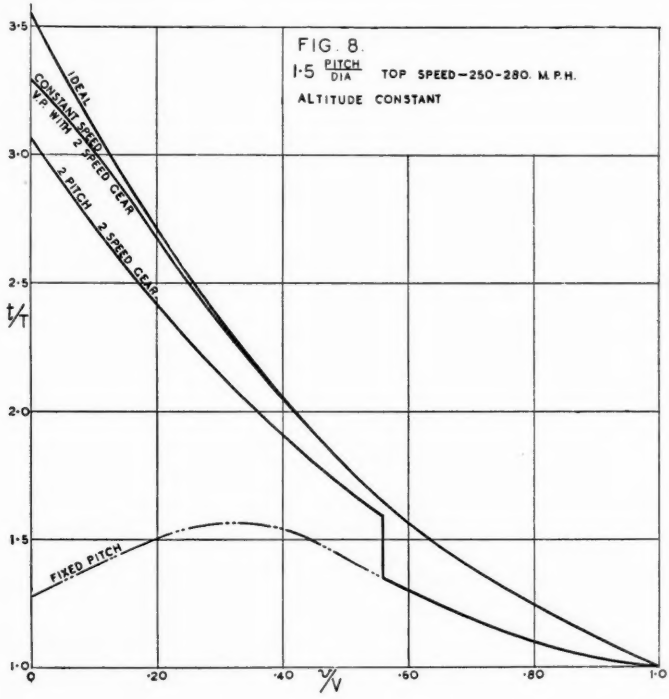
There is evidence and also experience which leads one to think that the curves used are not fully representative as regards static thrust of full-scale conditions. But in order to arrive at any relative results it has been found essential to use some set of curves based on tests of similar blades.

If, as I admit is possible, the stalling point is somewhat more delayed and the static thrust higher under full scale conditions, the various speeds I am quoting will alter, but the relative results will remain substantially the same.

(iii) Fixed Pitch and Variable Gear, (iv) Fixed Pitch—Two-Speed Gear.

There has from time to time been discussion as to whether a two-speed gear would constitute an alternative to variable pitch. The answer is definitely "No," because it does not prevent the airscrew blades stalling. The purpose of the two-speed gear is to allow the engine to maintain maximum r.p.m. in spite of the airscrew running slower. The increase in power will slightly increase the airscrew speed and will result in an increased thrust, but this increase in the static rate of rotation causes the airscrew to commence stalling at an even higher speed than before.

Fig. 7 shows the improvement in thrust due to the use of a two-speed gear for an airscrew of 1.5*D* pitch (aircraft speed 250-280 m.p.h.). To make a fair comparison it is again assumed that the second gear will come into operation on climb at a speed between 0.55 and 0.6 of the top speed. The result compared with the two-pitch shown in Fig. 6 is scarcely worth the expenditure and weight involved. It forms no alternative to a variable pitch or a two-pitch airscrew, and the more difficult and complicated suggestion of a variable gear automatically changing to keep the engine revolutions constant is little better. The static thrust in the case chosen is 1.29 for the fixed pitch, 1.48 for the two-speed gear, 1.56 for a variable gear, compared with 3.54 for the ideal.



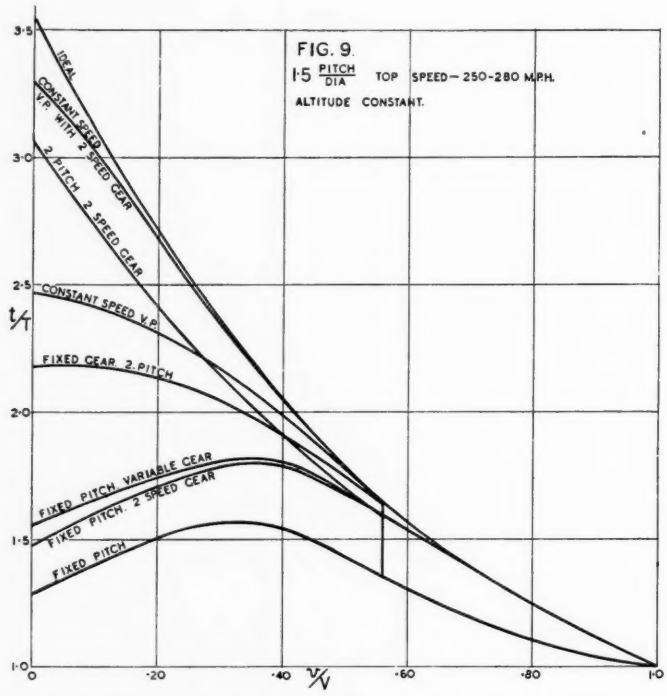
(*v*) *Two Pitches—Two-Speed Gear*, (*vi*) *Variable Pitch Two-Speed Gear.*

As an alternative to variable pitch there is no field for the two-speed gear, but it has a field, and for high-speed aircraft a very valuable field, as an addition for use with variable pitch. Indeed, I hope to show that by a combination of these two devices the ideal thrust curve can be closely approximated to.

In referring to the performance of the two-pitch airscrew, it was shown that for speeds of 250 m.p.h. or more, even in the second pitch, the blade would stall on the ground. In order to prevent stalling it is necessary to drop down to a pitch of 1.0*D* or less. To do this with the fixed gear engine would mean over-revving the engine on the ground. This could be prevented by introducing a second gear which would allow the airscrew to run faster to the necessary extent, but with the engine kept to its permissible r.p.m. For the case under consideration I have used a gear of 1.235, and thus have been able to drop down from a high pitch of 1.5*D* to a low pitch of 0.8*D*, a pitch which is well out of stall for all conditions of flight. An even better result would be obtained by using a

higher gear and dropping to a still lower pitch, but there are obvious limits to such a procedure. The lower the second pitch the higher the airscrew revolutions, and either very high tip speeds would be encountered at low speeds (a condition in which high tip speed is most detrimental), or alternatively the primary rate of rotation would have to be correspondingly lower with consequently larger and heavier airscrews. In this particular case if the tip speed in the second gear is 900 feet/sec., then the tip speed in the designed condition will be 730 feet/sec.

Fig. 8 shows how closely these combinations approach the ideal. The static thrust of the fixed pitch, two-pitch two-speed, and ideal are 1.29 3.06 and 3.54 respectively. To complete the story note the thrust curve for the constant speed variable pitch with two-speed gear with its static value of 3.3, an increase of 256 per cent. over the ordinary fixed pitch and within 7 per cent. of the ideal.



The two-speed gear together with variable pitch has a further advantage. The airscrew runs in its top gear only for take-off and climb, but most of its flying is done in the low gear with a reduction of 20 per cent. in tip speed. Apart from improved efficiency, the airscrew will be less noisy, a point of importance for both military and civil aircraft.

Fig. 9 shows the thrust curves of all the various combinations superimposed.

Fig. 10 shows similar thrust curves for the same combinations, but for an airscrew with a pitch of 2.5D corresponding to a speed of 450 to 500 m.p.h. The general order of merit remains the same, but their relative values have altered. All combinations except one are now stalling badly. The exception is the constant speed airscrew on the two-speed engine, which follows closely the ideal curve.

Fig. 11 shows the opposite end of the range illustrated by thrust curves for an airscrew with a pitch of 0.7D, corresponding to 110 to 120 m.p.h. In this

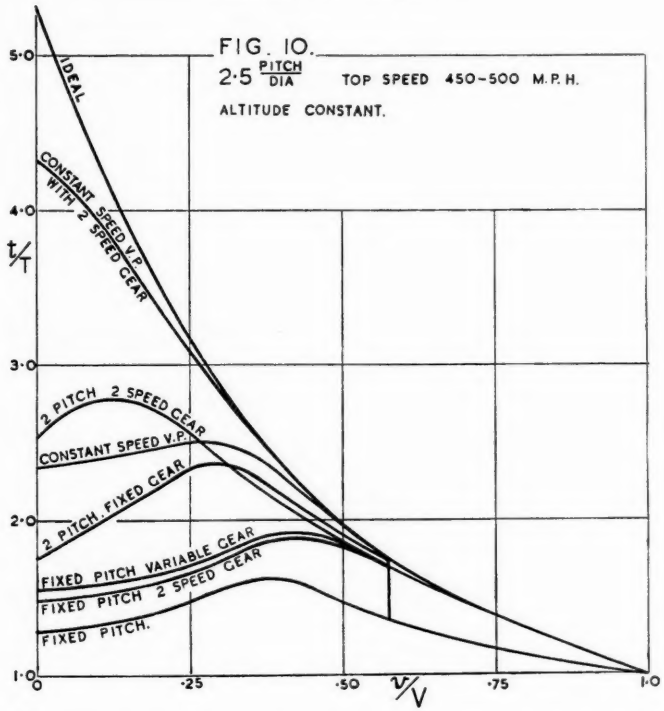


FIG. 10.
2·5 PITCH/DIA TOP SPEED 450–500 M.P.H.
ALTITUDE CONSTANT.
IDEAL
CONSTANT SPEED V.P. WITH 2 SPEED GEAR
2 PITCH 2 SPEED GEAR
CONSTANT SPEED V.P.
2 PITCH. FIXED GEAR
FIXED PITCH VARIABLE GEAR
FIXED PITCH 2 SPEED GEAR
FIXED PITCH.
t/T
5·0
4·0
3·0
2·0
1·0
0
·25
·50
·75
1·0
V/V

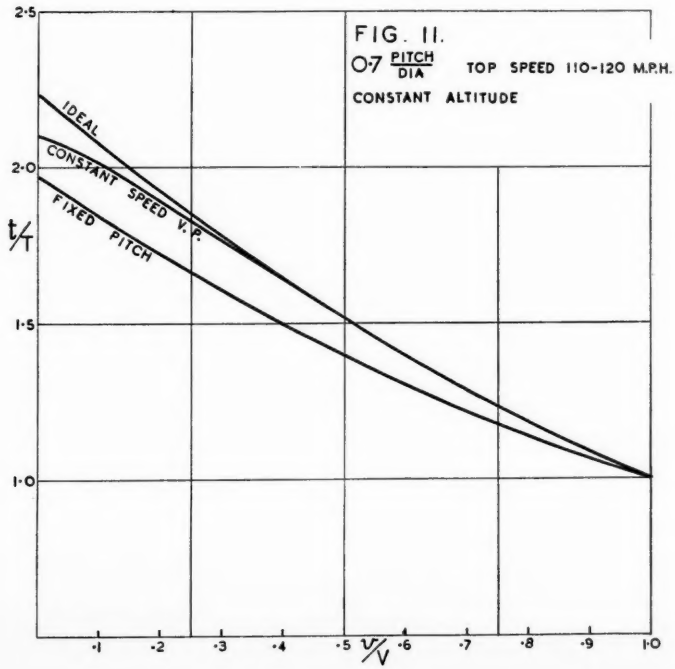


FIG. 11.
0·7 PITCH/DIA TOP SPEED 110–120 M.P.H.
CONSTANT ALTITUDE
IDEAL
CONSTANT SPEED V.P.
FIXED PITCH
t/T
2·5
2·0
1·5
1·0
·1
·2
·3
·4
·5
·6
·7
·8
·9
1·0
V/V

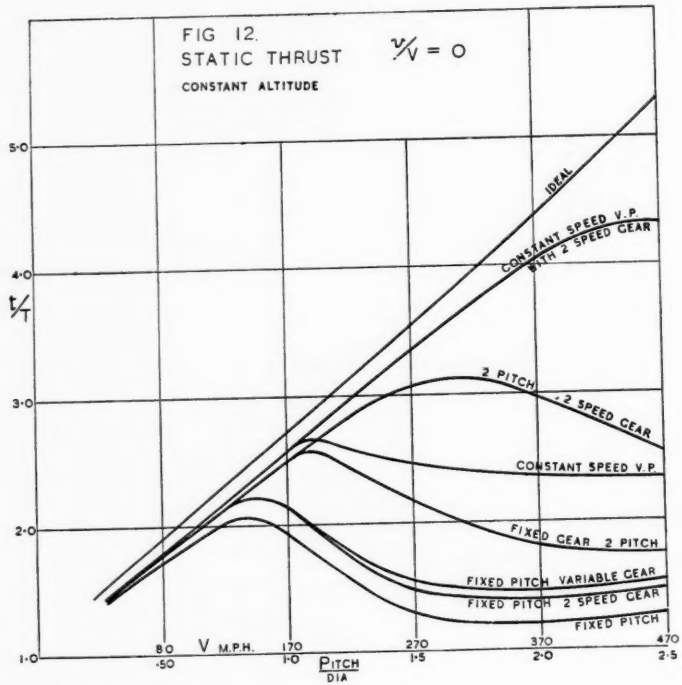


FIG 12.
STATIC THRUST $\frac{v}{V} = 0$
CONSTANT ALTITUDE
IDEAL
CONSTANT SPEED V.P WITH 2 SPEED GEAR
2 PITCH 2 SPEED GEAR
CONSTANT SPEED V.P
FIXED GEAR 2 PITCH
FIXED PITCH VARIABLE GEAR
FIXED PITCH 2 SPEED GEAR
FIXED PITCH
t/T
5·0
4·0
3·0
2·0
1·0
80 V M.P.H. 170 270 370 470
·50 1·0 1·5 2·0 2·5
PITCH / DIA

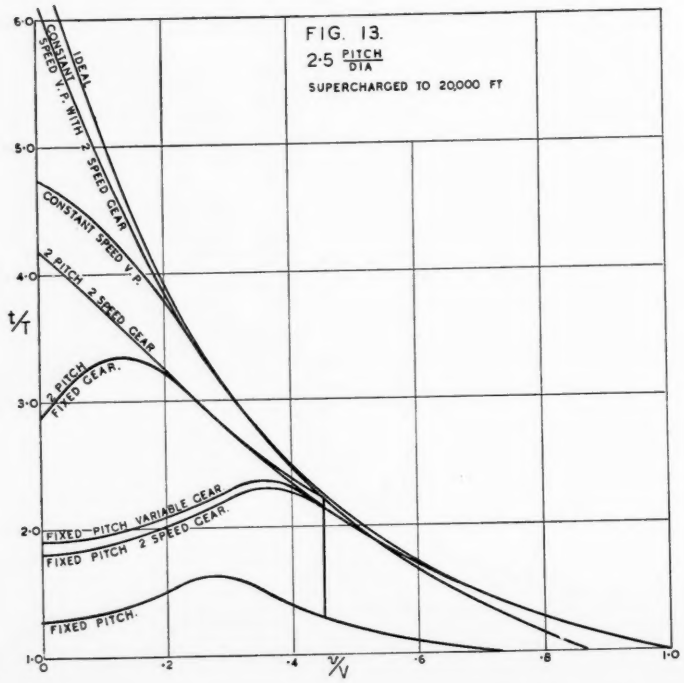
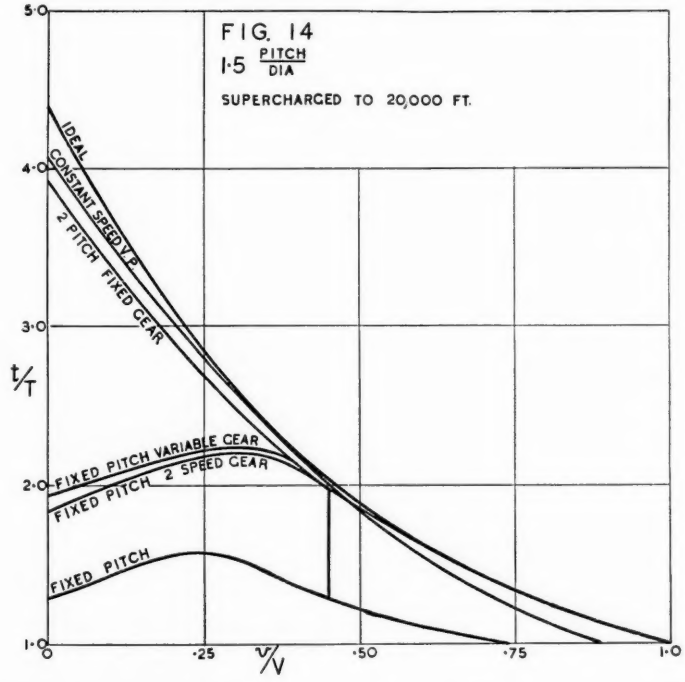


FIG. 13.
2·5 PITCH / DIA
SUPERCHARGED TO 20,000 FT
IDEAL
CONSTANT SPEED V.P. WITH 2 SPEED GEAR
CONSTANT SPEED V.P.
2 PITCH 2 SPEED GEAR
2 PITCH FIXED GEAR.
FIXED PITCH VARIABLE GEAR
FIXED PITCH 2 SPEED GEAR.
FIXED PITCH.
t/T
6·0
5·0
4·0
3·0
2·0
1·0
0 ·2 ·4 ·6 ·8 1·0
v/V

case all the curves lie so closely together (and are not all shown), and so near the fixed pitch airscrew that, as previously stated, the gain to be obtained by variable pitch or variable speed is not worth the price to be paid.

The question of immediate interest is at what speed does variable pitch become worth while and at what speed may we expect the further addition of a two-speed gear to become desirable? This can best be answered by reference to Fig. 12, which shows the static thrust plotted against pitch. To give a more readily appreciated meaning, a scale of approximately corresponding speeds has been added. The fixed pitch airscrew designed for a top speed of 140 m.p.h. gives a static thrust equal to nearly 90 per cent. of the ideal. Whatever gain is



possible can be obtained equally well with variable pitch or two-speed gear. Fig. 12 further shows that variable pitch, either in the two-pitch or constant speed form, only meets the full requirements for a small range of aircraft with speeds of 140 to 200 m.p.h. Above 200 m.p.h. it falls well below the ideal curve. The two-pitch coupled with two gears continues to do well up to 300 m.p.h. Beyond this the field is held alone by the constant speed type coupled with two gears. Above 400 m.p.h. even this combination shows signs of falling away. I have not thought it necessary to go further, but should mankind ever fly at over 500 m.p.h. a demand will probably arise for three gears, if the present type of airscrew has not by that time been replaced by some other form of jet propulsion.

Let me make it clear at this point that my statements are only true and general when I confine myself to talking in terms of pitch/diameter ratio. I am translating these ratios into terms of miles per hour to give a more readily appreciated meaning of my remarks. The speeds given infer that normal tip speeds are between 800 and 900 feet per second. For engines geared to give

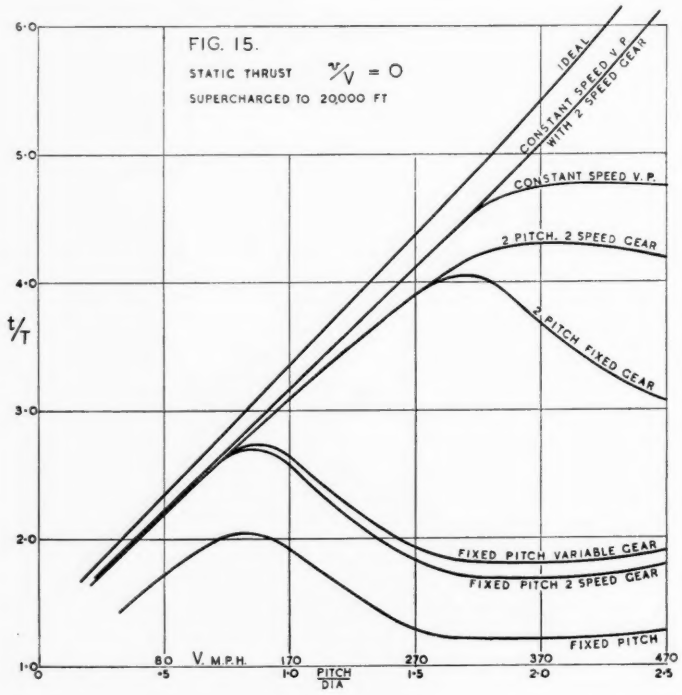
lower airscrew tip speeds the general conclusions still apply in terms of pitch diameter ratio, but the figures in m.p.h. must be suitably altered.

Speaking therefore in terms of pitch diameter ratio, I would sum up generally for the non-supercharged or very mildly supercharged engine as follows:—

If the aircraft under consideration is or would be fitted with an airscrew having a maximum pitch less than its diameter, the value of fitting a variable pitch screw is very doubtful. If it has a pitch greater than its diameter it is worth while, and becomes more and more essential as the pitch increases. If the maximum pitch is greater than $1.3D$ a two-speed gear in the engine becomes desirable.

(*b*) Supercharged Engine.

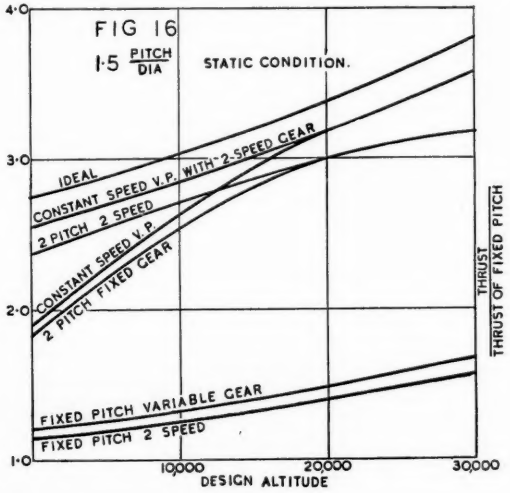
So far my remarks have been limited to non-supercharged or moderately supercharged and ground boosted engines. I now proceed to the case of the



supercharged engine, and here again it has been found necessary, because of the variation in degrees of supercharging, to assume a hypothetical engine which I think does not so greatly differ from the average supercharged engine as to invalidate my remarks. The engine assumed is supercharged to give at 20,000 feet the same power as at sea level.

The airscrews considered are designed to run at low maximum engine r.p.m. flying level at 20,000 feet. Fig. 13 shows the thrust curves for an airscrew with a pitch of 2.5, and Fig. 14 for 1.5 diameter. The climbing speed at sea level is assumed as 0.45 of the top speed at 20,000 feet. Fig. 15 shows the static thrust at sea level plotted against pitch, and as in Fig. 12 a scale of speed assuming a tip speed of 850 feet/sec. is added. The thrust is expressed in terms of the thrust

in the designed conditions, *i.e.*, in terms of the thrust at maximum r.p.m. at maximum level speed at 20,000 feet. The first thing to note is that, whereas for the unsupercharged engine the fixed pitch static thrust for a pitch $0.7D$ was 87 per cent. of the ideal, for this supercharged 20,000 feet case it is 77 per cent. of the ideal. There is therefore a stronger case for the V.P. airscrew for low pitches. Further, as before at these low pitches, any of the combinations give much the same result, which for practical purpose equals the ideal. Nevertheless, it still remains true that the gain at these low pitches is relatively small compared with the value of variable pitch on the higher pitch screws. I think my previous conclusion still remains true that for pitches below $1.0D$ it is doubtful whether the cost of the V.P. is worth the gain. Above this pitch, or 140 m.p.h. at 20,000 feet, this doubt disappears. The two-pitch continues to give a static thrust closely approaching the ideal up to about 300 m.p.h., and the constant speed up to 330 m.p.h. Above this the two-speed gear with the constant speed variable pitch becomes desirable, but the two-speed gear with the two-pitch airscrew is inferior to the constant speed with a single gear. Again, note the ineffectiveness of the two-speed or variable gear with a fixed pitch airscrew.



As compared with the non-supercharged engine, the main points to note are that variable pitch in some form becomes desirable at much the same pitch, *i.e.*, approximately 150 m.p.h., but the two-speed gear does not become worth while until 300 m.p.h. or over, as compared with about 200 for the non-supercharged.

In Fig. 16 I have connected up the two cases, unsupercharged and supercharged, to 20,000 feet. The curves show for various altitudes of supercharging the ratio of static thrust with each of the various combinations to the fixed pitch static thrust. The airscrew used for illustration has a pitch of one-and-a-half diameters, corresponding approximately to 250 to 280 m.p.h. at the various altitudes. The main purpose of this Fig. is to show that there is an altitude of supercharging at which the value of the two-speed gear disappears altogether. For this particular airscrew it is approximately 18,000 feet.

Finally I would say that it is one of the difficulties and dangers of talking on the performance of airscrews that there are so many variables and so many permutations and combinations. It is impossible in a limited set of curves to cover the whole range, and yet such a limited consideration leaves room for misunderstanding and criticism. For instance, I have been unjust to the fixed pitch airscrew. I have given throughout the static thrust of such airscrews

designed primarily for the highest maximum efficiency between climb and top speed, but the fixed pitch static thrust can be appreciably improved by designing for the best possible efficiency at take-off, consistent with limiting the revolution at top speed at the rated altitude to the permitted maximum. On the other hand, the static thrust of variable pitch airscrew can be increased by making the optimum efficiency occur at an even lower proportion of the top speed than has been assumed, provided a small sacrifice in top speed is accepted.

I trust therefore that in your criticism you will bear in mind the difficulties of presentation in a paper so limited in length.

I should like to thank all who have in any way assisted me in its preparation. Mr. Johnson, of the Royal Aircraft Establishment, and Mr. Devereux, of High Duty Alloys, for information; Messrs. The Airscrew Co., the de Havilland Aircraft Co., the Bristol Aeroplane Co., and Messrs. Gustav Schwarz for use of slides; but above all Mr. F. C. Lynam, A.F.R.Ae.S., who did the computations represented by the curves in Section 3 and who wrote the appendix on the hollow steel airscrew. Without his general help and assistance it would have been quite impossible for me to complete this paper in the time at my disposal.

Notes.

(1) Les Comptes Rendus de l'Academie des Science, 1892.
(2) Aeronautical Research Committee R. and M. 328, 1916-17.
(3) Aerofoil and Airscrew Theory. H. Glauert, 1926.
(4) Aeronautical Research Committee R. and M. 786, 1921-22.
(5) ,, ,, ,, ,, 829, 1922-23.
(6) ,, ,, ,, ,, 892, 1923-24.
(7) ,, ,, ,, ,, 1673, not yet published.
(8) On the Vortex Theory of Screw Propellers. Proc. Royal Society, A., Vol. 123, 1929, and
Aeronautical Research Committee R. and M. 1377, 1931-32.
(9) ,, ,, ,, ,, 1674.
,, ,, ,, ,, 1675.

Appendix I.

Properties of Airscrew Materials.

(All stress figures are in lbs. per square inch.)

Mahogany.

In tension—	
Limit of proportionality	5,000 to 10,000
Ult. strength	12,000 to 20,000
Young's modulus	1.4 to 1.8×10^6
In compression—	
Limit of proportionality	about 3,000*
Ult. strength	6,000 to 8.000
Specific gravity	0.52

The figures quoted for mahogany are approximate ranges within which timber to 4 V.7 may be expected to lie. The figure marked* was obtained for a specimen which gave an ultimate strength of 6,000 lb./sq. in.

Compressed and Impregnated Wood.

In tension—	
Limit of proportionality	7,500
0.1 proof stress	26,000
Ult. tensile stress	32,500
Young's Modulus	3.85×10^6
In compression—	
Ult. strength	23,000
In shear—	
Across grain	15,000
Along grain	4,000
Specific gravity	1.4

ALUMINIUM ALLOYS.

Duralumin—Specification DTD.150.

Chemical composition—

Copper	3.5 to 4.5 per cent.
Manganese	0.4 to 0.7 ,, ,,
Magnesium	0.4 to 0.7 ,, ,,

Impurities—iron—not more than 0.75 per cent.

Special properties—

	Longitudinal.	Transverse.
0.1 per cent. proof stress, tons per sq. inch	13.5	—
Maximum stress, tons per sq. inch	22.5	17
Elongation, per cent. on 2in.	15.0	4

All the above are minimum figures.

Fatigue strength—

±9.5 tons per sq. inch at 20 million reversals.

Hiduminium R.R.56—Specification DTD.184.

Chemical composition—

Copper	1.5 to 3.0 per cent.
Nickel	0.5 to 1.5 ,, ,,
Magnesium	0.4 to 1.0 ,, ,,
Iron	0.8 to 1.4 ,, ,,
Titanium	0.02 to 0.12 ,, ,,
Silicon	Not more than 1.0 ,, ,,

Physical properties—

	Longitudinal.	Transverse.
0.1 per cent. proof stress, tons per sq. inch	20	—
Maximum stress, tons per sq. inch	27	25
Elongation, per cent. on 2in.	10	5

The above are minimum figures.

Fatigue strength—

±10.5 at 20 million reversals.

In both the above the specifications call for a longitudinal test on both tip and boss of the blade, and transverse on the boss end only.

MAGNESIUM ALLOYS.

Extruded by the "Mitchel" Process.

Alloy—

Aluminium	5.00 per cent.
Manganese	0.36 ,, ,,
Silicon	0.026 ,, ,,
Iron	0.06 ,, ,,
Magnesium	Remainder

Physical properties ($3\frac{1}{2}$in. dia. root)—

	C.R.L.	T.P.R.	5.L.	E.L.
Limit of proportionality T/in.^{2}	3.7	1.8	4.7	4.7
0.1 per cent. proof stress T/in.^{2}	7.8	5.2	10.0	10.2
0.5 ,, ,, ,, ,, ,,	10.8	7.4	12.4	13.4
Max stress	16.7	17.2	18.2	18.4
Elongation per cent.	8.0	21.5	18.0	10.0
Young's modulus lb./sq. in. ÷ 10^6	6.0	6.4	5.9	6.2

C.R.L.—Longitudinal from centre of root.
T.P.R.—Transverse, from root and parallel to blade.
5.L.—Longitudinal from 5in. from root.
E.L.—Longitudinal from tip of blade.

SAME PROCESS. Alloy 4 per cent. aluminium (average tests 68 blades)

	0.1 % Proof Stress, tons per sq. in.	0.5 % Proof Stress, tons per sq. in.	Max. Stress, tons per sq. in.	Elongation %.
L.R. ...	4.5 to 6.0	6.0 to 8.0	14.0/18.0	9.0/18.0
T.R. ...	4.5 to 5.0	5.0 to 8.0	14.0/16.0	9.0/18.0
L.T. ...	6.0 to 8.0	8.0 to 9.0	14.0/17.0	12.5/19.5

L.R.—Longitudinal at root.
T.R.—Transverse at root.
L.T.—Longitudinal at tips.

Fatigue strength approx. ±7.5 tons/sq. in. at 20 million reversals.

GERMAN MANUFACTURE—FORGINGS.

Alloy A.Z.M.—

Aluminium	10.0 per cent.
Zinc	1.5 ,, ,,
Manganese (max)	1.0 ,, ,,
Impurities (max.)	1.5 ,, ,,
Magnesium	Remainder

Physical properties (test cut from root of blade)—

	Max. Stress, tons per sq. in.	Elongation on 50 mm.	Brinell Hardness, 10/500/15.
1.	20.32	15.5	62
2.	20.20	13.0	68
3.	20.12	13.2	67
4.	20.00	15.2	62
5.	20.12	12.4	67

AMERICAN MANUFACTURE (FORGED HOT AND PRESSED).

Alloy—

Aluminium	8.0 to 8.5 per cent.
Zinc	0.1 to 0.5 ,, ,,
Manganese	0.3 ,, ,,
Magnesium	Remainder

Physical properties—

	Hub Section.	Blade Section.
Yield point tons/sq. in. minimum ...	12.5	13.5
Max. stress ,, ,, ...	19.0	20.0
Elongation	5 to 6.0	6 to 8.0
Brinell (500 kg.)	70 to 75	70 to 75
Charpy impact ft./lbs. minimum ...	2.0	2.0

MICARTA.

As obtained in tests of samples cut from experimental airscrew blanks. These properties may be taken as representative of good quality synthetic resin materials bonded with fabric:—

Limit of proportionality (tensile)	1,600 to 2,000
0.1 per cent. stress (tensile)	6,000 to 6,800
Ult. tensile strength	13,500 to 15,500
Young's modulus	1.2 to 1.4 × 10^6
0.1 per cent. proof stress (compression) ...	About 6,000
Ult. compressive strength	,, 25,000
Specific gravity	1.35

Appendix II.

Estimation of thrust from torque and thrust coefficient curves, assuming engine torque constant with rate of rotation.—If ρ, V, N, K_q, K_t and J are the relative density, airscrew rate of rotation, torque and thrust coefficients, thrust and V/nD respectively for the design conditions and v, n, k_q, k_t, t and j similar values for any other condition of airscrew working at ground level, then

$$v/V = (j/J)\,(n/N)$$
$$t/T = (k_t/\rho k_t)\,(n/N)^2$$

To evaluate n/N

(*a*) Fixed pitch.

Since $\rho k_q N^2$ is constant.

$$(n/N)^2 = \rho K_q/k_q$$

(*b*) An airscrew with any device for maintaining the engine rate of rotation constant.

Since power is constant.

$$\rho K_q N^3 \text{ is constant.}$$
$$(n/N)^3 = \rho K_q/k_q$$

(*c*) Two-speed gear.

With airscrew in gear ratio G.

Airscrew torque = engine torque/G.

$$\therefore k_q n^2 = K_q N^2/G$$
$$\therefore (n/N)^2 = (K_q/k_q)\,(1/G)$$

In the text, page 492, a statement is made that to achieve maximum efficiency the torque coefficient curve of the ideal airscrew must be that represented by the line X.X. Fig. 3, since at any value of V/nD this line corresponds to maximum efficiency.

This statement is not strictly true, because with changing airscrew speed combined with constant engine revolutions we are concerned with maximum efficiency not at a given value of V/nD, but at a given value of V. The correct torque curve for maximum efficiency at any given aircraft speed is given by line K.K. as shown below.

For a constant speed engine, a given airscrew blade, and a given efficiency to determine the value of k_q to give maximum thrust.

For a given efficiency and power

$$T \propto (1/V) \propto (1/JN)$$
$$k_q N^3 \text{ is constant}$$
$$\therefore T^3 \propto (K_q/J^3)$$

Hence the point of any curve of maximum efficiency to give maximum thrust per horse-power is where K_q/J^3 is a maximum.

To determine for any airscrew blade the value of static K_q and K_t to give the maximum static thrust for a given power.

$$T \propto K_t N^2$$
$$K_q N^3 \text{ is constant}$$
$$\therefore T^3 \propto (K_t^3/K_q^2)$$

Hence thrust is a maximum when K_t^3/K_q^2 is a maximum.

Appendix III.

The airscrew known by the name of Lietner-Watts, manufactured by Metal Propellers, Ltd., Croydon, was the only type of hollow blade to make any progress in this country. Mild steel was used for manufacture because it was essential to have a material which could be welded satisfactorily.

The early type was of the two-blade integral pattern; although satisfactory as regards performance, it did not lend itself to the standardised production

essential for commercial success. In 1920 therefore this type was abandoned in favour of the detachable and adjustable blade airscrew.

The form of this later blade was similar to the conventional blade shape. At the inner end, however, the cross section became circular, and on this portion a cylindrical steel sleeve was fitted machined to suit the hub sockets. The centrifugal load was taken on a collar formed integral with this sleeve and transmitted to a corresponding shoulder on the hub. The blades were hollow, comprising

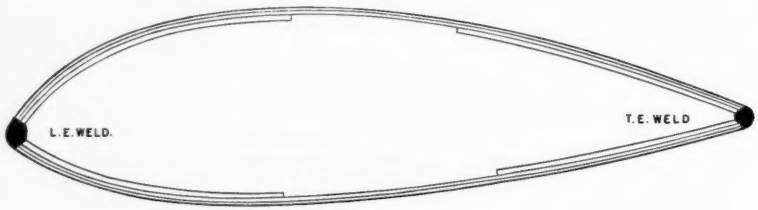


FIG. 17

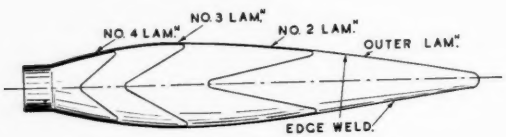


FIG. 18.

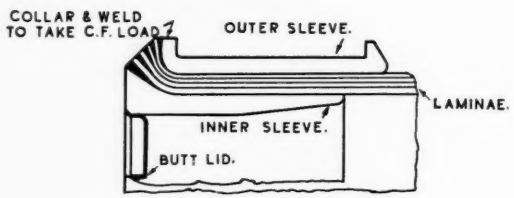


FIG. 19.

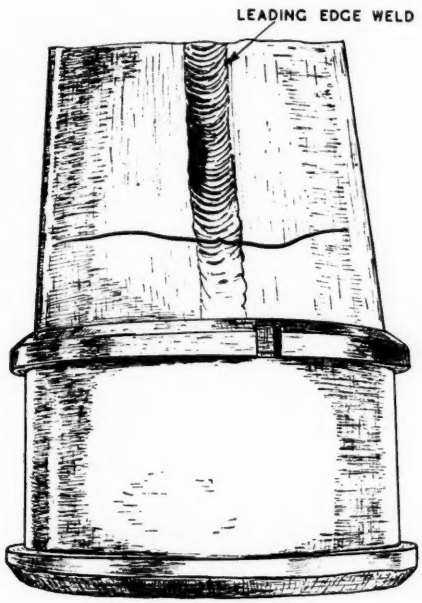
two pressings—one " back " and one " face." These were made up of three or four laminæ cut from a mild steel sheet. The laminæ composing the pressing varied in length. The outer one which formed the aerodynamic surface was unable to sustain its own loads and was reinforced by the inner laminæ. The first extended to about three-quarters of the blade radius, the lengths of the remainder being settled by questions of stress distribution. The ends of the inner laminæ were forked to avoid any sudden change in stress.

The component pressings were welded together at their meeting edges, forming leading and trailing edge welds. Fig. 17 shows a cross section of the blade after welding, and Fig. 18 an inside view of one pressing indicating the varying lengths of the component laminæ. After welding, inner and outer root sleeves were fitted, both of which were welded to the blade laminæ (see Fig. 19). This weld takes the centrifugal pull of the blade. No case is known of this attachment having failed.

After welding, heat treatment was carried out and distortion rectified. This process of re-shaping required great skill and much experience. Correct track and alignment was obtained by machining the root sleeve after fitting.

An outstanding feature of these blades was the method of balancing. The moment of every blade of a type was constant about the axis of rotation, and the centre of gravity in the same plane of rotation. It was balanced vertically in two planes at right angles to each other and horizontally, resulting in true dynamic balance.

FIG. 20



Among the more important modifications adopted during development were the following:—

(1) Change from the " concave " to " bi-convex " aerofoil section.
(2) Long root sleeves abandoned in favour of the short type.

(1) The concave blade face required internal support necessitating the use of struts. It was difficult to design a strut to withstand indefinitely the effect of centrifugal loads. Failure was precipitated owing to the blade sheets having to be pierced. The twisting of the blade while under load and the extension of one sheet relative to another due to unequal loading caused the struts to rock, these ultimately fractured, or caused the sheets to crack. The effect was greater on engines which had a large torque variation.

Bi-convex sections were finally adopted to give the blade sufficient initial stiffness, and struts were no longer necessary. Slack metal formed on the " face " after re-shaping was " taken up " by swaging corrugations, thus further increasing stiffness.

(2) The length of the hub socket necessary to transmit safely the torque from engine to blade was settled originally more or less by guesswork. Inferior cooling, due to the large centre portion being ineffective, caused the question of

shorter sleeves to arise. Subsequently two blades were made up and fitted to a special hub, having sockets of half the original length forming an airscrew 11ft. 6in. diameter. It was tested on a 400 h.p. Liberty used for routine spinning of metal airscrews. The engine was opened up to maximum speed, *i.e.*, 1,400 r.p.m.; switched off, throttle closed to give 800 r.p.m.—engine nearly stopped—cut in on switch—burst to 800—sudden opening of throttle. Further burst to 1,400—switch off. The test commenced with this cycle at twice a minute and was increased finally to six times a minute. In ten hours the cycle was completed 1,785 times, 720 of which were done in the last two hours. It is doubtful whether any airscrew has ever been submitted to so severe a test. Examination showed no sign of wear or crushing on the hub or sleeves. The roots were perfectly circular.

It was therefore decided to manufacture a series of standard blades embodying these modifications. Each type was submitted to a 50-hour bench test, and in some cases extended to 150 or 200 hours. Failures were, however, experienced in the air in less than 100 flying hours and, as with other metal airscrews, these failures were generally catastrophic. Failure occurred either just outside the root sleeve (see Fig. 20) or on the " pressure face " near the tip. The latter was caused primarily by lack of stiffness in the blade " face " which allowed " breathing " or " panting " set up by the effects of torque variation.

In general, the failure of the Lietner-Watts hollow airscrew can be attributed to fatigue caused by a fluctuation of stress in the torque plane and resulted either from natural periods, or from forced vibrations set up by engine impulses. As the blades were quite stiff in this direction, the stress became very high before deflection was great enough to permit the damping action of centrifugal force.

The design of hollow steel blades also became increasingly difficult owing to the advent of nose diving manœuvres in service.

Discussion.

Mr. F. W. Johnson (*Associate Fellow*, Royal Aircraft Establishment): It was impossible to deal with the subject fully in one paper, but Dr. Watts had wisely concentrated on the very important problem of the improvement of the take-off. Whatever improvement was attained, no doubt aeroplane designers would want more; therefore, they should try not only to give the best, but to indicate the probable limitations. From that point of view Dr. Watts had made a most valuable contribution. He had shown that increase of r.p.m. was of definite advantage in take-off, and this suggested a line of development for engines with fixed gears, if it was desired to avoid the complications of two-speed or variable gears. Brief reference had been made to the possibility of improving take-off by sacrificing a little top speed performance; the improvement was effected by increasing the diameter or blade area of the airscrew, and the loss in top speed was very small. Mr. Johnson raised this question because he considered that the need for the two-speed or variable gear on load-carrying aeroplanes was rather less than was indicated by the curves in the paper, and he asked if Dr. Watts would comment on that matter. Much the same effect was obtained by designing for altitude; the diameter, and hence the static thrust, increased with design height, and at some height, as shown by the lecturer, the need for the two-speed gear disappeared.

The use of Schwarz covering as a means of attaining thinner sections was interesting, as they might wish to use higher tip speeds with wooden airscrews. Mr. Johnson asked how much thinner a mahogany blade and a light wood blade could be with this protective covering.

The Schwarz detachable blades were a little disappointing from the point of view of weight, but the reduced inertia was of distinct advantage. The blades were still experimental in this country, but a three-bladed airscrew of this type was under test at the R.A.E. and so far no signs of trouble had been detected.

With regard to the various materials for airscrews, the suggestion contained in the last column of Table II, that micarta was not so readily available as magnesium alloy, steel and Schwarz wood, was a little surprising. He asked why micarta was placed so low in order of availability.

Mr. F. M. THOMAS (*Associate Fellow*, the de Havilland Aircraft Co.): He asked if Dr. Watts would agree that the importance of the blade element theory had been exaggerated considerably, because, whilst that theory told them why an airscrew did what it did, it told them little about how to design an airscrew practically. For instance, it was inclined to be misleading in regard to the best shape of blade root. Furthermore, it was usually best to obtain aerodynamic data from full-scale tests. One used the blade element theory to get the equations by which to reduce the test data; but he believed it was possible to develop adequate equations from the dimensional theory.

It was interesting to hear that the Schwarz covering was as resistant as metal to erosion and abrasion; but he imagined that, to be really practical, it should be much more resistant than metal, because it was so difficult to dress it down and repair it after it had been subjected to erosion and abrasion. Further, it had been rumoured that Schwarz covering cracked, and even that some of it had been flown off. Mr. Thomas asked for an estimate of the number or proportion of failures (if any) that had occurred.

In the paper there was a tendency to emphasise that Schwarz covered wooden airscrews were particularly adapted to large designs. He pointed out that there was nothing to prevent the use of metals for large airscrews, because the stresses in geometrically similar blades are the same if the tip speeds are the same and aerodynamic considerations will lead to the use of nearly constant tip speeds. Mr. Thomas imagined that the saving of weight resulting from the use of Schwarz covered wood as compared with duralumin would tend to become appreciable at diameters such as 50ft. Duralumin blades up to 18ft. diameter, which is large enough for all immediate needs, had been built and found to be quite successful; on the "Akron," the large dirigible, the diameter of the forward propellers was 18ft. and that of the propellers in the slipstream was 16ft. No trouble had been experienced with them.

The quotation from the American maintenance instructions did give a rather bad impression as set out in the paper; but Mr. Thomas pointed out the instructions were written for mechanics, and were in the same category as were the instructions to pedestrians to take special notice of the street signs in order that they should be able to cross the streets safely. One might gather from the maintenance instructions that the position with regard to propellers was more dangerous than in fact it was; there had been very few failures, and perhaps one reason for that result was that such instructions had been issued. Perhaps one reason why instructions must be framed so carefully was that mechanics were not accustomed to consider the airscrew as part of the power plant assembly; if they did so, and gave it the same attention, the service it would give would be roughly the same. He did not remember the relative proportions of forced landings on the part of air line machines due respectively to engines and to propellers, but he felt certain that the propeller proportion was very small. Of course, the time period between overhauls was at the discretion of the designer, and a conservative designer might fix the period at 200 hours, whereas he might take a little chance and fix 500 hours. Generally the period between overhauls in the case of airscrews worked out at about the same as in the case of the high-powered engines. During 1934 United Air Lines had 115 controllable pitch airscrews in service, which gave an accumulated service of a quarter of a million flying hours. Some had been used for 3,000 flying hours, but the average service of the propellers during the year was 2,100 flying hours. There has never been a failure of a Hamilton standard controllable pitch airscrew which has resulted in loss of life or serious injury. A life of 3,000 hours flying

was a certainly long life for a wooden airscrew, as Dr. Watts had said; but it would probably tend to be on the low side for metal airscrews.

Mr. Thomas complimented Dr. Watts upon his courage in having reproduced, in Tables I and II, practically the same tables as those of Mr. Caldwell, there being only slight changes. But one was a little surprised to find that wood ranked so high as was indicated, especially in comparison with Schwarz covering. Micarta was not a very commonly used material; it was worth looking into, but one could not expect a great deal from it. It was of roughly half the specific gravity of duralumin, whereas the specific gravity of magnesium was two-thirds that of duralumin; but design considerations, when using micarta, called for the use of a greater quantity of material than when using duralumin, so that by the use of micarta one did not realise a 50 per cent. saving of weight, but an average saving of 15 or 20 per cent. if one were lucky, and sometimes less than that. There were other materials having about 1/35th the weight of duralumin. For example, he mentioned the hydrogenated rubbers, in the use of which there seemed possibilities of development. He asked for Dr. Watts' comments as to their suitability. Micarta requires considerable development for use in airscrews. Why should they not rather take a long jump to a material weighing about 1/35th as much as duralumin and offering possibilities of a much greater saving of weight? The problem was not so much one of the strength/weight ratios of the materials as one of creep characteristics.

During the last year a great deal had been done with regard to splines, and two standards were being generally worked to, under the influence of the Air Ministry—a tapered spline and a straight spline. Particulars could be obtained from the Air Ministry.

It did not appear to be quite fair to refer to the " Hamilton " as the two-pitch type and to the " Curtiss " as a good example of the constant speed type, because at the moment the " Hamilton " was the only one with a constant speed device in service.

One could say very little about the aerodynamical calculations. They were very clever, for it is difficult to weed out the minor variables, as Dr. Watts had done. In general one must agree with the conclusions arrived at.

Mr. Thomas said he had used methods different from those used by Dr. Watts for calculating the characteristics of airscrews, and his conclusions had shown the same trend as those of Dr. Watts. Of course, the calculations must not be interpreted rigidly, and it would certainly be found that there were many border line cases for which controllable pitch airscrews might or might not be used at the request of the operator.

A most important point was that over-revving was a substitute for a two-speed gear, and Mr. Thomas doubted that it was worth while to undertake the weight of the two-speed gear. He believed it preferable to get the engine manufacturers to arrange for increasing the r.p.m. at take-off, and mentioned the efforts of the Air Ministry in this regard during the past year.

Mr. C. C. WALKER (*Fellow*, the de Havilland Aircraft Co.): According to the paper the metal blade made a rather poor show, and he agreed that when one could substitute a vibration damping material it would be a very good thing. But he did not think they would be able to get away from the need for inspection and maintenance; they might be able to ease up a bit with regard to the blades, though not very much. From the very nature of variable pitch propellers, their inspection and maintenance would always be a serious business. With regard to micarta, one should remember that it was just a stock electrical insulation material, and they could not expect too much of it at the moment as a material for making propellers. But Mr. Schwarz had already shown what could be done with fibres and resin, and presumably the whole of that field was open. It might be difficult to cope with the low elastic modulus of micarta, but no doubt that would be improved; but, even if it were not, it had been shown by Dr. Watts that they could change from metal, which was liable to crystallisation and fatigue,

to a vibration absorbing material, even if they did not decrease the total weight. The de Havilland Aircraft Company had been running three different variable pitch propellers lately, and the results seemed very promising. One had the aluminium alloy blades, another the Schwarz blades, and the third had Bakelite blades. All of them had been operating in a " Hamilton " hub. The blade weights of these particular propellers were such as to produce centrifugal loads of 15 tons in the aluminium alloy blade, 14 tons in the Schwarz blade and 12½ tons in the Bakelite blade. The two latter blades, of course, were very experimental, and there was every prospect of the figures being improved, especially for the Schwarz blade, which he suspected was of too great a size for the particular engine used.

Dr. Watts had asked for indulgence on account of the complexity of the various factors entering into the diagrams shown in the paper; but he need not have asked for indulgence, for never before had Mr. Walker seen such a mass of complex information presented so clearly and so well. His subsequent remarks on this aspect of the problem, he said, would not be made in any critical spirit, but they might be regarded as illustrating the extent to which the various factors might be " wangled." The de Havilland Company was looking into a project involving the use of variable pitch propellers, where the maximum designed speed was about 220 m.p.h., and it was found that there would be only 3lbs. per h.p. static thrust, which was far too small and was inadmissible; the ideal curve put forward by Dr. Watts probably gives between 4¼ and 4½lbs. per h.p. static thrust. The two-speed gear had at once suggested itself, and the company had gone so far as to apply for a patent for the combination of a two-speed gear with a variable pitch propeller, in which the engine was geared up to the propeller for take-off. That was done merely to prevent other people preventing the company doing what it wanted to do! But now that Dr. Watts had very thoroughly effected publication of this idea, the company could save any further expenditure on a patent! Major Halford, the company's engine designer, after looking into the problem of applying the two-speed gear, had asked if it would not be just as good to increase the take-off r.p.m. It would be just as good, and that was what Dr. Watts had referred to as " over-revving "; but it ceased to be " over-revving " when legitimised by type test. It was necessary that a tip speed of 950ft. per second should not be exceeded at any time during the take-off, not only on account of noise but also on account of loss of efficiency, and that the tip speed under operating conditions should be less than 750ft. per second. If all these conditions were met, the static thrust would be 4lbs. per h.p., which was all they could expect to get and was quite near Dr. Watts' ideal curve. These things did not conflict in any way with what Dr. Watts had said; indeed, they must agree entirely, because they were based on the same sort of considerations. But the moral which Mr. Walker wanted to point was the necessity for engine and aircraft designers to co-operate with the propeller designers when the question of rating engines for variable pitch propellers cropped up.

Mr. F. C. Lynam (*Associate Fellow*): He had had the pleasure of assisting Dr. Watts in the preparation of the paper. Frequently comparisons were made between the weights of relative airscrews, particularly detachable blade types, and more often than not wrong conclusions were drawn. It was practically impossible to make a comparison of weight unless each type had the same designer and provided that the design conditions and aerodynamic considerations were identical. For example, the Schwarz detachable blade, which could be fitted to a fixed pitch or variable pitch hub, would probably be designed for a normal tip speed of 900ft. per second for maximum loading conditions at take-off, and also for nose-diving at 20 per cent. in excess of maximum r.p.m. It was impossible, therefore, to compare the weight of such a blade with that of a type designed for a constant speed variable pitch hub where maximum revs. were not exceeded and where probably a definite h.p. had been used for the maximum

loading condition. Mr. Walker had mentioned the Schwarz blade for the Gipsy Six. That particular blade could absorb 400 h.p. (static) when running at 950ft. per second tip speed, and one doubted whether it was comparable with the other blade Mr. Walker had mentioned. It would seem that there must be some mistake in regard to the figure of 14 tons quoted as the centrifugal pull on the Schwarz blade, because the calculated figure is approximately 9.5 tons.

In comparing weights, one must remember that owing to the excessive weights of metal airscrews every means had been used to save weight, hence thin sections and narrow blades. The wooden airscrew designer had not worried about weight; if and when he did, reasonable savings could be made, within the limits provided by flutter.

With regard to larger sizes of metal blades, the problem was not only one of weight; there was also the difficulty of obtaining large forgings which were sufficiently homogeneous. The manufacture of all metal blades must be perfect if small nicks and indentations which precipitated failure were to be avoided. Happily, in the case of the Schwarz detachable blade one was not hampered by these conditions and the only limit of size was tip speed, and owing to the absence of dies for manufacture one could design the best possible blade for the particular specification considered.

Referring to Part III of the paper, Mr. Lynam said one might infer that for an aircraft with a top speed of 150 m.p.h. or more a variable pitch airscrew was necessary. Actually, an interceptor fighter with a top speed of 300 m.p.h. might attain a normal take-off with a fixed pitch wooden airscrew, and this might mean a virtual saving of 200lbs. in weight. On the other hand, a flying boat or air liner with a top speed of 250 m.p.h. might need a two-speed gear in addition to variable pitch.

Part III of the paper indicated the need for close co-operation between the aircraft, engine, and airscrew designer, each case being treated on its merits. In addition, ground clearance, noise, selection of gear ratios, location of pusher or tractor screws must be considered.

Mr. J. L. Hodgson (*Associate Fellow*): He was interested in the application of the celluloid surface impregnation method—originally evolved for making imitation bone shaving brush handles—to the surfacing of airscrews. He suggested that a Bakelite surface impregnation, though more difficult to effect and less pleasant to look at, might be found to have better qualities with respect to hardness, peeling and anti-corrosion. He asked to what extent the celluloid finish was satisfactory when exposed to large temperature variations.

With regard to the main part of Dr. Watts' paper, which dealt with various methods of securing adequate thrust at low speeds in machines designed for high speeds, he would like to ask Dr. Watts if the possibility of over-revving the engine, when getting off and at low speeds, had been sufficiently considered. If over-revving was used as an alternative to the gear change proposed by Dr. Watts, it did not mean that the over-revved engine had to deliver more power. Hence such questions as additional cooling for the pistons did not come in. The main question to be considered was whether it was mechanically simpler and constructionally lighter to provide bearings and crankshafts which would stand up to temporary increases in the speed of 20 to 30 per cent. than it was to provide a two or three-speed gear device. In the case of supercharged engines, the fact that the power might fall off at the higher revs. owing to the greater air velocity in the intake pipes could be fairly easily dealt with.

The whole question of over-revved engines combined with variable pitch propellers, therefore, seemed worthy of careful investigation.

Mr. Hodgson desired to congratulate Dr. Watts on the extremely clear presentation of a mass of data, and on the logical and fascinating way in which the paper led up to definite and practicable conclusions.

Mr. C. H. Griffiths (*Associate Fellow*): With regard to the reference in the paper to certain wooden airscrews giving a flying life of something over 3,000

hours, he thought there were many people who would like to obtain some of those airscrews! He asked for information as to the sizes of those particular airscrews, the power of the engines on which they were used, the manner in which the timber was protected, and whether special precautions were taken during manufacture to match the various laminations used. A flying life of 3,000 hours for any airscrew was good, but for a wooden airscrew it was very good; though it would be appreciated by some that the figure was exceptional for a wooden airscrew, Mr. Griffiths felt that by reason of the manner in which it was mentioned in the paper Dr. Watts might produce, unwittingly, a false impression concerning the average life of a wooden airscrew. Mr. Griffiths doubted that the average life of a wooden airscrew exceeded 300 hours, and prior to the presentation of the paper he had never heard of one having completed 1,000 flying hours.

Apart from accidental damage, wooden airscrews fitted with segmented sheaths failed due to (1) the sheaths cracking or ballooning at the tip, and (2) the timber cracking beneath the sheathing, usually from screw or rivet holes. These cracks might be commenced occasionally during the fitting of the sheath, or later due to shrinkage of the wood beneath the sheath. He anticipated that those types of failure would be eliminated almost entirely by the use of the Schwarz finishing process.

Another type of failure which nowadays was causing really serious wastage in wooden airscrews was the shrinkage cracking of the timber at or near the boss, and most frequently inside the boss bore. That trouble was a serious handicap to the use of British-made wooden airscrews at overseas stations. Preliminary experience seemed to indicate that the Schwarz finished integral airscrew was not altogether free from shrinkage failures, and he asked Dr. Watts if he had any hope of overcoming the trouble in the Schwarz airscrew.

In view of the foregoing remarks, Mr. Griffiths felt rather doubtful, as did Mr. Thomas, whether the wooden airscrew was correctly placed in Table II under the heading of "Dependability." He asked why Dr. Watts had placed the Schwarz wooden airscrew in that table as being less dependable than the ordinary wooden airscrew, for he would have thought that, in view of the improved blade protection and the much improved metal sheathing, the Schwarz wooden airscrew would have been the more reliable.

Although it would be agreed that the most serious failures in the Leitner-Watts hollow steel airscrew were due to transverse fractures at the blade roots, Mr. Griffiths said he seemed to remember that there had been rather more failures along the welded edges than was suggested in the paper.

Mr. HOLLIS WILLIAMS (*Associate Fellow*): Although Dr. Watts, in his interesting series of diagrams, had stressed the importance of static thrust, he should not focus his attention upon this factor to the exclusion of the performance of the airscrew at higher speeds. It was of no great value to achieve a phenomenal amount of static thrust, because most machines operating from normal aerodromes could be taken off with ease, and in any case static thrust was unlikely to be a criterion for design as the high wing loading which would be encouraged by the presence of such a thrust would be limited by the subsequent landing. The speaker suggested that Dr. Watts should concentrate on obtaining maximum thrust at speeds between 80 and 100 m.p.h. This was particularly important in the case of twin-engined aircraft, in order to achieve single engine flight, and this was likely to be the main criterion for design of all such aircraft. At such speeds shown by Dr. Watts on his charts as between 30 and 50 per cent. of the maximum speed, it will be noticed that there is very little digression between the thrust curve for a normal variable pitch airscrew and the ideal curve, and approximations thereto obtained by variable gears in addition to variable pitch, and it is suggested that except in a few very special cases, this extreme refinement of the thrust curve at low speeds will be found unnecessary. It was obvious to everybody that variable pitch airscrews on modern high speed aircraft

were a necessity. There is no doubt that existing variable pitch airscrews form a very complicated manufacturing problem, but it did seem that the whole industry was being held to ransom, judging by the prices that were being asked.

Anybody, therefore, sponsoring a new and cheaper type of construction, as was Dr. Watts, deserved the thanks and co-operation of the whole industry.

Mr. C. F. Hodson (*Associate Fellow*): It was disappointing that Dr. Watts, who was so ardent a protagonist of the metal airscrew, should have devoted so little attention to the work done in developing the twisted duralumin airscrew in this country by the Fairey Aviation Company, and particularly by their former chief technician, the late P. A. Ralli. Mr. Ralli's work in supervising the design of metal airscrews for the Schneider Trophy races had been rightly recognised by the Society, inasmuch as it had presented him with its Silver Medal. Whilst it was difficult to give due recognition to all parties in the course of a paper so condensed as that by Dr. Watts', one felt that Mr. Ralli's work on racing airscrews, which had done so much to enhance the prestige of the nation in the aeronautical world, should have received preferential treatment.

Mr. Ralli, who had possessed a most charming personality, had been a very clever mathematician, as was exemplified by his method of determining the stresses and deflections of airscrew blades (published by the Society). He had also operated upon a form of absolute torque coefficient—obtained by dividing the usual torque coefficient by J^5—and had obtained generalised formulæ and curves for the most efficient airscrew for any conditions without being restricted to a particular blade form or number of blades.

Whilst his work on airscrew stressing might appear cumbersome, it had paved the way for an extremely accurate later development of systematic successive approximations, retaining all the essential features which he had set out so clearly, but reducing the actual work to one-tenth. Having been associated with Mr. Ralli in this work and also in his investigations into long-range aircraft, Mr. Hodson regretted that Mr. Ralli's work should have been so completely ignored in the paper.

Herr Hoffman: Like Dr. Watts, he had begun his early propeller experience in the development of metal airscrews. For several years he had designed airscrews of the hollow steel type, which he had abandoned for reasons similar to those responsible for the abandonment of the Leitner-Watts in this country. Next, he had turned his attention to light alloy airscrews and had achieved practical results with a design incorporating a steel hub and detachable light alloy blades with the pitch adjustable on the ground, and this type had still a limited use. On joining his present firm, Messrs. Schwarz, who, as purely airscrew makers, were interested in all useful varieties of airscrew, in addition to his task of improving wooden airscrews, which were the firm's main products, he had had the opportunity for an unbiased study of the capabilities and development prospects of wooden airscrews as well as airscrews made of the various metals and other materials. Although the efforts of the firm had led to no substantial improvements in metal propellers and, in fact, since that time (1928) there had been no marked advance in metal propellers, the firm's development of the wooden airscrew had resulted in astounding improvement, which had changed the whole future outlook. They had developed a method of constructing wooden propellers free from the former disadvantages associated with that material, and there were practically unlimited possibilities for development, particularly in the direction of detachable blades for variable pitch propellers. As a result, they had abandoned metal and had concentrated entirely on the new construction in wood.

Since 1930 airscrews of that construction had been adopted in several countries, and during the past six years many thousands of these airscrews had gone into service, giving very satisfactory results. Not only had the wooden airscrews been adopted for normal service, but in recent times they had been used increasingly for specially severe conditions where formerly only a metal airscrew

would have been considered practicable. For example, the L.H. South Atlantic service, on which the metal propellers were replaced, in 1933, by Schwarz wooden airscrews, had reported a gain in performance and complete satisfaction in regard to durability, under exceedingly trying climatic and other service conditions. In fact, the large majority of all German seaplanes and flying boats were equipped with Schwarz's wooden airscrews.

The achievement of an entirely satisfactory construction for light-weight wooden airscrews had coincided with the realisation of the future necessity for variable pitch, whilst the light weight of wooden blades and, even more important, the small centrifugal and gyroscopic forces of such blades, had brought at the same time the design of satisfactory variable pitch mechanisms much nearer. In this direction, the company had completed the development of detachable wooden blades for use in the various types of hubs and mechanisms favoured in different countries, and they had had over three years' experience with their detachable blades. These had been fitted to a variety of engines of powers up to more than 900 h.p., with excellent results. For some time these blades had been in serial production, and several hundreds had passed into service. Experimental blades of that construction were being produced also to fit the various special pitch mechanisms employed at home and abroad, even for the United States.

Whilst Messrs. Schwarz and other German firms were engaged on the development of infinitely variable pitch airscrews to meet all practical operating requirements, they had found it advisable to develop a simplified solution in the form of an automatic two-position mechanism, which in the meantime would give a substantial advantage for all purposes requiring variable pitch and at the same time fulfil a permanent requirement for many types of aircraft where a simple and less expensive accessory might be desirable.

Finally, Herr Hoffman said that during his visit to England he had again been pleased to see and privileged to experience the benefits of mutual technical co-operation in his own particular sphere. He and his compatriots looked forward to extended co-operation between the two countries.

Mr. T. E. Beacham (*communicated*): The Schwarz blades described by Dr. Watts appear to be a most promising and scientific solution of the detachable wooden blade problem which so many experimenters have tried without success. The reduction in centrifugal pull is of particular interest in the case of V.P. airscrews, where the hub and anti-friction bearings which have to sustain it form a substantial portion of the total weight of the airscrew. He would like to ask Dr. Watts how the centrifugal turning moment of these blades compares with that of the solid duralumin blade, as in many cases this is the most important factor in the design of the actual pitch changing mechanism.

Mr. R. M. Clarkson (*Associate Fellow*) (*communicated*): He was confining his remarks to Section III of the paper and would like to congratulate Dr. Watts on the extremely comprehensive review of the whole vital problem of airscrew and engine performance and the admirable way in which he has represented the relative merit of the numerous devices and combinations (Fig. 5 onwards).

So interesting are the curves in Fig. 9 that he had endeavoured to express very approximately their results in terms of pay load on an air liner. He had taken, as a basic machine representing current practice, one with maximum speed 250-280 m.p.h., which just clears the I.C.A.N. screen (20 m. in 600 m.) when fitted with two pitch propellers and fixed gear. He had then applied to this machine in turn each of the propeller and gear combinations illustrated on Fig. 9 and adjusted the all-up weight to maintain the take-off constant; the variation of structure weight with all-up weight to maintain constant factor of safety has been taken into account—no allowance has, however, been made for the varying weight of propeller and gear in each case. The results show roughly what the existing two pitch fixed gear combination has done for the modern

high speed air liner, and what remains to be gained by the various combinations of pitch and gear discussed in the paper.

Case.	Relative Pay Load.
Basic two pitch, fixed gear	1.0
Constant speed, fixed gear	1.25
Two pitch, two-speed gear	1.46
Constant speed, two-speed gear	1.70
Fixed pitch, variable gear	
,, ,, two-speed gear	
... .	0.48
,, ,, fixed gear	0.18

Dr. Watts' views on the importance of blade section would be very valuable. When comparing the two sources of data: N.P.L. (Tunnel), R.M. 1673, etc., and N.A.C.A. (Full Scale), N.A.C.A. 350, 481, etc., it appears that blade section must have a very important bearing on take-off thrust. The difference between the sections in the two series of tests is chiefly one of degree of thickness, both have flat under surfaces, but the N.P.L. sections are about 10 per cent. thick at 0.75 R. compared with $7\frac{1}{2}$ per cent. for the N.A.C.A. sections. There is very good agreement in static thrust at fine blade angles, but stalling commences about 3° finer on the N.A.C.A. sections. At 25-30° blade angle at 0.75 R. (about 1.0 P/D) the N.P.L. static thrust is about 20-30 per cent. greater than the N.A.C.A. If this is a real phenomenon and not partly due, as has been suggested, to tunnel interference in the N.P.L. tests, it is very important indeed, and provided that there is no great difference in maximum efficiency, seems to show that thick sections are far superior. As much as 3 per cent. loss of efficiency at cruising to maximum speed with thick sections compared with thin only represents about 2 m.p.h. loss of speed, and would be fully counterbalanced by the greater pay load possible. What are Dr. Watts' views on this point?

He was a little puzzled at the apparent slight increase of static thrust with increase of speed for the fixed pitch propeller at speeds above about 370 m.p.h., shown in Figs. 12 and 15. Can this be due to the fact that the blade has become so completely stalled in the static condition that the fall off of static thrust (t) with increase of design speed is less than the fall off of design thrust (T)?

Mr. C. N. H. Lock (*Fellow*) (*communicated*): He wished to make a strong appeal to the lecturer and to other designers of airscrews to make use of methods based on airscrew vortex theory in place of the purely empirical and graphical methods in use at present. Up till quite recently the use of the vortex theory was subject to two very serious disadvantages:—(1)The agreement between theory and experiment was by no means exact for high pitch airscrews; (2) the labour of applying the formulæ was almost prohibitive. The former objection had been shown in a recently published paper to be almost entirely removed by the use of a correction for tip loss, based in a logical manner on the general vortex theory; the labour of applying the formulæ would be enormously reduced in two different methods involving the use of charts for which he hoped to publish complete numerical data in the near future. The simpler of the two methods (referred to in the first section of the lecture) had been applied successfully to the case of the stalled airscrew and was then almost indispensable because of the large variation of performance with blade section beyond the stall which had been observed in recent model experiments and also in the American propeller research tunnel. This method would, for example, be most useful in extending the range of calculations such as those in Part III of the lecture. This was not the place to go into further detail on the subject, but he earnestly hoped that in a few years' time all designers of airscrews would make much greater use of theoretical methods than they had done in the past.

Mr. G. T. Lampton (Aviation Manufacturing Corporation) (*communicated*): He felt that Dr. Watts' paper raises a number of points which require expansion

to avoid misleading the reader who is not entirely familiar with propeller matters. Particularly, the order of merit assigned to the hollow steel blade should be challenged. He concluded that these positions were based upon blades produced by the Leitner-Watts process, and were not intended to be a reflection on the advantages inherent to hollow steel blades generally.

The mass fatigue strength ratio is doubtless the best single criterion of the suitability of a propeller material. In the United States no one would consider using other than a highly alloyed steel heat treated to an absolute minimum of 135,000 pounds per square inch. If we take the fatigue limit of wood at one-third of the modulus of rupture, steel is distinctly superior to wood and should head the specific fatigue column of Table I. It is also necessary to note that the aluminium alloys are over-rated since twenty million stress cycles are entirely inadequate to determine the endurance limit. At half a billion cycles the stress-cycle curve is not horizontal, and in this country, there is some dispute among metallurgists as to whether these alloys have a true endurance limit or not.

A large number of hollow steel blades are flying in the United States and compete with dural both in weight and efficiency. When certain factors damaging to the endurance limit have been eliminated, they can confidently expect a substantial reduction in the weight of these blades and a material improvement in efficiency. Whether they can compete with the Schwarz type will depend principally on the volume of production and the economics of the specific aeroplane, *i.e.*, the weight which can profitably be added for a given increment in efficiency.

Hollow steel blades, due to the high modulus of elasticity and efficient disposition of material, are more rigid than any of the other types under discussion. Wooden blades, particularly those treated with plastics of low modulus of elasticity and a density greater than wood, will have low fundamental frequencies which, in direct drive applications, will approximate the engine speed. The higher modes of vibration of such blades will also generally be of lower frequency, and therefore the operating range free from resonance will be narrower. Although hollow sections do introduce transverse stresses because of sectional "breathing," the designer has an added variable for control of vibration characteristics in that the moments of inertia can be maintained or increased while the unit weight is reduced.

With regard to the desirability of providing a controllable propeller with a two-speed drive, it should be noted that the gearing is helpful only during take-off, and the principal improvement is in static thrust. Mr. E. P. Hartman in "Considerations of the Take-off Problem," N.A.C.A. Technical Note No. 557, shows that stalling to the extent of losing two-thirds of the static thrust, while it increases the "unstick" time due to reduced acceleration, has only a small effect on the length of the take-off run. This distance is the measure of safety, and one must be on guard not to be misled by static thrust ratios.

The paper is a distinctly valuable contribution to propeller literature in that it shows at a glance the relative merit of the several propulsive arrangements discussed, and the author deserves the thanks of the industry.

Mr. R. T. Youngman (*Associate Fellow*) (*communicated*): Although it may be true to say that the flexibility of the Reed airscrew has certain drawbacks, it has one very definite advantage in that when a machine decides to stand on its nose the airscrew provides an excellent shock absorber, often without serious injury to itself. Metal airscrews have been bent almost double and afterwards repaired.

The Reed type of airscrew is one in which the necessary rigidity is mainly derived from centrifugal forces. The Fairey metal airscrew has for some time departed from the Reed principle, and although it still retains its advantage over the wooden airscrew, from the point of view of efficiency, its inherent stiffness is such that it does not rely on centrifugal bending moments to attain the necessary rigidity.

The question of balance is not so serious as the author would lead them to believe. The three-blade metal airscrew, which has recently been developed by the Fairey Company, has shown itself to be particularly smooth running in service. The term dynamic balance is a misnomer, and really implies three-dimensional static balance. That is static balancing in the plane of rotation in addition to the two other planes of reference. Because of the wide variation of the ratio between thrust and centrifugal force under the varying conditions of flight, unbalanced dynamic forces arising from unequal flexure of the blades under load could only be balanced for one particular condition. There is a danger even that the weights or other means adopted for this particular condition would accentuate the unbalance under other conditions, as, for instance, if the masses were applied to correct unequal flexure under static conditions, they would aggravate the unbalance in the dive when the centrifugal forces are not only greater, but the thrust is reversed.

It has been found sufficient to balance airscrews in the plane of rotation by means of a special machine which works at very slow rotational speeds, about one rev. per second. The process is very simple and airscrews balanced in this way are found to be perfectly smooth in operation.

He did not agree that it is more difficult to meet exact design requirements with wooden than with the twisted metal airscrew. The latter has a distinct advantage over the wooden airscrew in that the calculated pitch of an experimental airscrew may, if found necessary, be changed by retwist after flight test. This advantage frequently saves valuable time.

The author has remarked about almost unlimited possibilities of the Schwarz type of airscrew. He would like to ask whether it would be possible to design an airscrew of this type similar to those made in light alloy for the Schneider Trophy aircraft.

Reply to the Discussion.

In reply to some of the questions raised, I will deal first with Mr. Johnson's reference to increasing the static thrust by sacrificing somewhat the top speed. That, he said, had been indicated very briefly in the latter part of the paper, and he agreed that if one adopted that course, the value of the two-speed gear became less. For the purposes of the paper he had adopted a common design point for all the combinations, and his curves could be repeated by anyone on the basis of a lower design point.

Replying to the question as to how far one could reduce the thickness of blades by using the Schwarz covering, he said, by about 10 per cent. of the present wood thickness. But he relied upon the Schwarz covering, not so much to reduce the blade thickness as to enable him to use a narrower blade without giving rise to flutter.

The statement that the weight of the Schwarz detachable blade was somewhat disappointing had been answered by Mr. Lynam. It should be borne in mind that in bringing the Schwarz detachable blades to this country, time had been the essence of the contract; for that reason he had used blades having larger roots than he would use normally if he were in production. The size of root used on the 800 h.p. propeller, referred to by Mr. Johnson, should normally be capable of transmitting 1,500 h.p. on three blades. Again, all such blades as he had put into use so far had been designed to withstand the highest possible tip speeds for both normal and nose-diving conditions of flight. He would ask whether comparable blades had been designed for the same conditions. To Mr. Johnson's question as to why micarta was placed so low in order of availability, he replied that the basic material in micarta was linen fabric and that this was definitely an imported material which could not be grown or otherwise manufactured in this country.

The answer to Mr. Thomas' question as to whether in the paper the value of the blade element theory had been exaggerated was very definitely "No." Dr.

Watts considered that the blade element theory had been of great service. He did not claim that everyone used it in detail—admittedly he did not—but it had enabled us to understand the airscrew problem and had indicated the lines of research. If it were applied practically, with all the modern factors, it gave amazingly good results in spite of interference variations.

On the question of the resistance of the Schwarz covering to erosion and abrasion, he had been deliberately modest in not claiming more than equality with metal. Since he was challenged he would venture the opinion that it was more resistant. He could hardly imagine the necessity of ever having to dress it down, as suggested.

Dr. Watts welcomed the opportunity to deal with rumours of failures of the Schwarz covering. He believed Mr. Thomas must have in mind a particular experimental propeller to which an admittedly excessive amount of cellulose paste had been added over the true Schwarz cover at the tip. This additional paste had broken off. Dr. Watts feared no challenge when he stated that in no case had a Schwarz covering ever come off a blade. In some cases, he admitted, it had cracked, but investigation had shown that in such cases the propeller was fluttering or resonating. The cracking of the Schwarz covering provided a warning which would not otherwise be given of such a condition.

With regard to the investigation of the possibilities of materials having 1/35th the weight of duralumin, he said that such very light materials had been investigated from time to time and there was no reason why one should not continue to investigate them. Probably the difficulties were creep and flutter when using such materials having a low modulus of rigidity.

Commenting on Mr. Walker's reference to micarta, and the statement that the material used was only stock insulating material, Dr. Watts pointed out that 17 years had elapsed since the micarta screw was first made, and he doubted whether the material had changed much during that period. If it were to take a place in the airscrew field, much more research must be done.

Discussing Mr. Walker's reference to centrifugal pulls of 15, 14 and 12½ tons respectively on the aluminium alloy, Schwarz and micarta blades, Dr. Watts said that a most careful investigation showed that the centrifugal pull on the Schwarz blade referred to by Mr. Walker was 9½ tons. Here again the size of root was large enough for a 400-500 h.p. engine. Had a smaller root been available it could have been used with considerable saving of weight.

In view of Mr. Hodgson's suggestion that possibly impregnation with Bakelite would be better than impregnation with celluloid, Dr. Watts said it appeared that a wrong impression had arisen. The root of the detachable Schwarz blade was not impregnated with celluloid. He had referred in the paper as a special preparation, and it differed very little from Bakelite

Mr. Hodgson asked how the celluloid finish was effected by changes of temperature. Dr. Watts stated he had an open mind. The effect was being watched in both hot and cold climates. So far nothing detrimental had been reported.

To Mr. Hodgson's further question, the lecturer replied that the object of the two-speed gear was to allow the propeller to run faster without over-revving the engine. If, therefore, over-revving is permissible to that extent the two-speed gear is unnecessary.

Although Mr. Griffith had expressed surprise at the figure of 3,000 hours as representing the life of a wooden airscrew, it could be taken as a fair figure, given the same degree of maintenance and attention as would be given to a metal screw. Such figures had actually been achieved by Messrs. Imperial Airways on propellers of approximately 11ft. 6in. diam. operating on Bristol engines, not in the home country but across Africa. He admitted that taking the flying world as a whole the average figure was very much less, but this in his opinion was a question of maintenance.

The placing of the " Schwarz wood " below " wood " in the table on dependability is admittedly a mistake which will be corrected, but apart from this, Dr.

Watts maintained it was a correct placing. He would ask Mr. Griffith to consider the very great care taken both by calculation and test before giving approval to a metal airscrew and the admitted necessity of careful maintenance afterwards and then to contrast this with the nominal approval procedure necessary for a wooden design. He could count on the fingers of one hand the number of cases of wooden propellers failing in the air during the whole of his 20 years' experience.

Replying to Mr. Griffiths' question as to whether the cracking of bores in wooden propellers would be overcome by the Schwarz process, Dr. Watts said he thought it would. He admitted that so far they had not fully covered the Schwarz propeller in the bore itself. The very fact that the propeller was Schwarz covered and could not exchange moisture with the outside air so rapidly meant that it would probably exchange moisture more readily from one lamina to the other; therefore, greater care was being taken to ensure that the moisture contents of the individual laminæ were the same. With that precaution, and the precaution of covering the bore with celluloid, he believed they would be able to eliminate the cracking of the bores of wooden propellers.

Written Discussion.

I think Mr. Williams' criticism is very pertinent and I am grateful for it. I have, perhaps, over-emphasised the importance of static thrust by cross plotting only for this condition in Figs. 12 and 15. Similar cross plotting can be done for various percentages of the forward speed. The conclusions I leave to the aircraft designer. I have supplied the data.

Mr. Hodson's complaint that I had ignored Mr. Ralli's work is difficult to answer. I was dealing very briefly with past achievements in order to devote more attention to present and future developments. There are many names which I might have mentioned had I been doing a historical survey, but if I have, by omission, done any injustice to Ralli, of whom I was a great admirer, I am glad that Mr. Hodson has repaired the omission.

Mr. T. E. Beacham.—The twisting moment of a Schwarz blade would be approximately 50 per cent. of that of the corresponding dural blade.

Mr. R. T. Youngman.—It is not my purpose in any way to belittle the Reed airscrew. I fully appreciate the advantages claimed, particularly the facility of adjusting the pitch by permanent twisting. All I wished to point out was that flexibility was not an unmixed blessing, and Mr. Youngman implicitly agrees when he says that the original extreme flexibility is not now adhered to or emphasised.

I think it would have been quite possible to design the Schneider Trophy airscrews in wood, particularly if Schwarz covered, and I should much have liked the opportunity of so doing. I do not think I should have improved the speed, but I should have improved the take-off.

I am indebted to Mr. Clarkson for transforming my figure into relative pay loads.

On the question of blade sections, my own full-scale experience leads me to believe that for take-off the conventional flat face section is preferable to the more modern Clark Y section. Also, as already stated in my paper, whilst thick sections have admitted disadvantages for maximum flying speed they do materially improve the take-off by delaying the stall. To the last paragraph Mr. Clarkson has supplied his own correct answer.

Mr. Lock's contribution calls for no answer, but I should like to take this opportunity of acknowledging the great help which I have always received from the N.P.L. in general and Mr. Lock in particular, and I emphasise his appeal by confirming that a close study of the papers issued by the Aeronautical Research Committee under his name will well repay careful study by every practical designer.

To Mr. G. T. Lampton I would say that the order of merit depends obviously on the quality of steel used. The order given applies to blades in which the necessity of welding limits the choice of material. I would add that on purely theoretical grounds a better case can be made out for the hollow steel propeller than any other type. For that reason we in this country pursued the line for many years. Only our actual experience disillusioned us. The shape of an airscrew blade is such that the actual distribution of stress throughout the thin sheets is anything but uniform.

The failure shown in the illustration in Appendix II of the paper is a fatigue crack, but I am of the opinion that due to the inevitable shape of the blade such high local steady stresses occurred at the point of failure that the permissible fatigue range was reduced to dangerous limits.

I will freely admit Mr. Lampton's point concerning the rigidity of the hollow steel blade. In my whole experience of hollow steel blades I have come across no case of flutter.

With his comment on the advantages or otherwise of the second gear with C.P. propellers I do not disagree. My main object was to supply the data in as clear a form as possible and leave the user to draw his conclusion. I have commented on this point in my reply to Mr. Hollis Williams. The second gear, however, does give an advantage on top speed by reducing the top speed with increase of efficiency and silence.

The PRESIDENT: He took the opportunity to remind the meeting that the Society was a scientific body, and he drew attention to a desire on the part of some speakers to boost their own goods in the course of discussions. It must be remembered that they were first of all scientists, and it was the purest fortune that the work they were doing for the advancement of science was in any way connected with some commercial enterprise!

A further point was that speakers in the discussions were not present to instruct the meetings; that was the function of the lecturers. There were many who appeared to think that it was their duty to present minor papers from the body of the hall. They should confine their remarks, however, to disputing with the lecturer certain points he had raised, or ask for information.

Having invited those who had not had the opportunity to speak to submit written contributions (to which Dr. Watts would reply in writing), the President said that the subject was so vast that the Society should have another paper with regard to it soon. Meanwhile, he expressed hearty thanks to Dr. Watts for his very helpful and thoughtful paper and for the very charming way in which he had presented it.

(The vote of thanks was carried with acclamation, and the meeting closed.)

The 598th Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS.

A meeting of the Royal Aeronautical Society was held in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, on Monday, November 25th, 1935, when a paper, "Comfort in Air Travel," was read by Dr. S. J. Zand, F.I.Ae.S.

In the chair: Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P., President of the Society.

The CHAIRMAN: Dr. Zand was aeronautical research engineer to the Sperry Gyroscope Co., in America. He graduated from the Federal Polytechnical Institute, Zurich, and did post-graduate work at the École Superieure d'Aeronautique in Paris. He went to America in 1925, and since 1931 had been engaged in research work for the Sperry Gyroscope Company. In 1931 he was awarded the Wright Brothers' Gold Medal for his paper before the Society of Automotive Engineers on "A Study of Instrument Boards and Aeroplane Vibration." Dr. Zand had sound-proofed the Curtis, Douglas, Martin, Fiat and Sikorsky machines and had just been engaged by the French Air Ministry to sound-proof all French machines of the 1936-37 programme.

COMFORT IN AIR TRAVEL

By STEPHEN J. ZAND, F.I.Ae.S.

When the Royal Aeronautical Society did me the honour several weeks ago of asking me to give a lecture on sound-proofing of aircraft, I hoped to be able to prepare a formal paper and read it to you. I did not realise at that time, however, that my temporary duties as consulting engineer to the civil aircraft division of the French Air Ministry would take practically all my time. So I arrived in London with only the scantiest notes and shall be obliged to talk more or less extemporaneously on the broader subject of comfort in air travel. I hope that I may have the opportunity to supplement this lecture by a more elaborate paper at a later time.

It is worth telling how the firm with which I am connected[1] conceived the idea of investigating this interesting subject of comfort in air travel; the story is typically American and serves to prove that investigations of this kind are possible only if all concerned with the problem co-operate to the fullest and put the interest of aviation as a whole before the consideration of material profit.

In 1931, one of the very prominent executives in the aircraft industry, and, I believe, a director in our company, took a transcontinental trip from Los Angeles to New York. The trip, some 2,700 miles, took at that time from 27 to 30 hours. (The aeroplanes used were the all-metal tri-motored Fords.) Commenting on his trip, he told us something we had never thought of before, namely: "The trip took me only 30 hours, but I was sick and unable to work for 48 hours afterwards, hence the effective gain in time over a train was only five hours. How under such circumstances can air travel and the civil aircraft industry prosper; how do we expect to build and sell engines, planes, landing lights, instruments and other equipment in any appreciable quantities?" First, he told us, you must sell to the general public many, many aeroplane tickets and then you may expect a growth of commercial aviation. "Get to work—make aeroplanes comfortable, as comfortable as other means of transportation, or else aeroplanes, except in cases of strict emergency, are doomed as passenger carriers." Being

[1] Sperry Gyroscope Company, Inc., Brooklyn, New York, U.S.A., and London, England.

practical, he appropriated a certain sum of money for a basic research and I was put in charge of this work.

Since neither my associates nor myself knew much about the subject, it was necessary to proceed extremely cautiously and methodically. First of all, we thought it necessary to gather and compare the opinions of other travellers to make sure that our patron was not a hypersensitive person, an individual whose nervous system was particularly sensitive to slight discomforts always encountered in transportation, and who might have had an exaggerated idea of the unpleasantness of air travel.

On American aeroplanes for many years now we have had, as part of the staff, " hostesses," young women of 20 to 30 years of age, generally trained nurses, whose duties are to make passengers " feel at home " aloft. These young women fill out on each trip a fairly exhaustive report dealing with the reaction of passengers, such as number of air sick, their criticisms of operation, service, etc. On some of the air lines, passengers are requested also to fill in a questionnaire in which the transport company asks for criticisms and suggestions. These files were made available to us, and after a few weeks of some clerical and statistical work we found out that in every one hundred cases about ninety would list " excessive noise," about seventy-three " poor ventilation," sixty-five to seventy " bumpiness," sixty " unevenness of temperature," and then all kinds of minor complaints having little or no bearing on our work. Some of the air lines circularised their clients, especially those who had travelled by air but once and asked why they did not use the aeroplane more often. In most cases the answers were close to the evidence disclosed by the statistics from our hostesses' reports. We had in a short time proved to ourselves that lack of comfort in air travel was a real and not an imaginary handicap to the development of commercial air line operation. Our findings were so interesting to some of our transport companies that we were assured of their support and active co-operation in the elimination of discomfort in air travel.

" Comfort is an inward feeling of well-being produced by receiving normal stimuli from outside."[2] What are the external stimuli to which one is subjected in an aeroplane? Listing them in the approximate order of importance as evinced by the opinions of a multitude of passengers we have:—

(1) Noise.
(2) Ventilation.
(3) Changes of the attitude of an aeroplane (bumpiness).
(4) Heat or cold.
(5) Improper seating accommodation producing muscular fatigue.
(6) Mechanical vibration.
(7) Rate of climb or descent.
(8) Altitude.
(9) Smell.

Some of the above-mentioned elements, such as noise, mechanical vibration are definitely interconnected, some of them, such as smell, can be treated separately; since I have occupied myself primarily with noise, mechanical vibration and ventilation, I will give those elements the most consideration. I must emphasise, however, that all the above items are important and that neglect of any of them may have serious consequences.

Noise accompanies all forms of transportation, and most of the noise in large cities is caused by vehicles such as tramcars, buses, trucks and passenger cars. In recent years, due to the great increase of high-speed vehicles in inhabited areas the noise became so great that the public began to grow extremely conscious of it. Everyone can observe that the faster the vehicle, the greater the noise it creates unless special precautions are taken. Before investigating noise inside

[2] Ref. 1. P. R. Bassett, " Passenger Comfort in Air Transportation," Journal Inst. Ae. Sc., February, 1935.

aeroplane cabins we wanted to ascertain what the physiological boundary of noise was or, in other words, we wanted to know how much noise an ordinary passenger can suffer without discomfort. We were interested to know also what, if any, is the real relation between speed and generated noise. To gather these data in 1932 was not very easy owing to the fact that measuring devices were not available and measuring units not clearly defined. It would be beyond the scope of this lecture to go into either one of these subjects. I refer the reader to already published material.[3] Suffice it to say that to-day, at least in the U.S.A., Great Britain, France and Italy, we have well established and standardised units, systems of measurements, and so forth, also there are on the market many excellent sound and noise measuring and even recording devices.

Table I shows very clearly that our observation regarding the increase of noise with speed holds pretty true. The slowest vehicle, an ordinary sailboat at 4 m.p.h., makes a total noise of 30 db., while the fastest—a twin-engine bomber at 230 m.p.h. causes about 110 db. or about 10^8 as much.

The table shows us that the range of noise levels with some exceptions, such as the underground and the sailboat, has the same order of magnitude for each form of transportation. The values appear to be highest in the fastest form of transportation, *i.e.*, air, and lowest in the slowest vehicles, *i.e.*, surface vessels. Another idea can be inferred from Table I, namely, that 75 db. of noise is about the threshold of unpleasant noises, in fact we have never heard any complaints from boat passengers and only rarely noticed criticism as to excessive noises in Pullman cars. When the noise level exceeds 75 db. then a large number of people begin to complain—thus, I was informed that untold numbers of letters were written by disgruntled patrons to a R.R. company in France which put in service a 100 m.p.h., but also 90 db., railcar. The company disregarded the warning, but soon had to retire those cars from service owing to the lack of passengers willing to patronise them.

Our goal in 1931-32 was set at 75 db. or a noise level which can be described as fairly comfortable, where conversation can be carried on in almost normal tones of voice at distances up to 10 to 12 feet. How this mark was surpassed in 1933 (Douglas DC-2), what means were used and developed so that now in 1936 we have reached 65 db. (Wibault 67C) will be told subsequently.

Led to believe by producers and distributors of acoustical materials that there are some magic products which, when wrapped around an aeroplane, will make the craft quiet, we made the same mistake as all other aeronautical engineers and searched vainly for such a material. We did not find it and we shall not find it, for, as we know now, a quiet cabin is not to be achieved by the mere application of a soundproofing material, no matter how good in itself, but we learned many things concerning these materials. We found, for example, that they can be classified and that each class will fill certain acoustical needs. Also from the different characteristics of those materials it is possible to predict beforehand their actual insulation values. We shall discuss this aspect later, and take up first the contributors to the general aeroplane din. Listing them in the order of their magnitude we have:—

(1) Airscrew	... ...	108 db.
(2) Exhaust	... ...	104 ,,
(3) Engine clatter	... ...	90 ,,
(4) Airborne noises	... ...	94 ,,
(5) Aerodynamic noises	...	80 ,,
(6) Ventilating noises	... ...	100 ,,
(7) Total noise	... ...	112 db.

[3] Ref. 2. "The Decibel," by the Author—"Sperryscope," Vol. 6, No. 11; also "The Decibel," by the Author—"Aeronautical Engineering," February, 1933, Vol. 3, No. 2, page 19; and "Du Decibel," by R. S. Lacape—"Revue de l'Armée de l'Air," No. 77, December, 1935, p. 1404; also "Electrical Engineering," November, 1933, and "Bulletin American Standards Association," July, 1933.

TABLE I.

SHOWING SPEED RANGE AND CORRESPONDING NOISE LEVEL OF DIFFERENT CLASSES OF VEHICLES.

Medium.	Year.	Vehicle.	Speed, m.p.h.	Noise Level at this Speed—db.	Range of Speed.	Range of Noise Levels—db.*	Comfort Level at Maximum Speed.	Conversation Level.
Air.	1935	Twin-engine bomber	230	110	70-250	75-115	Very painful.	Impossible to converse even by shouting.
,,	1929	Tri-motor 12-passenger transport ...	110	105	60-125	75-115	Very painful.	Impossible to converse even by shouting.
,,	1928	Bi-motor six-passenger transport ...	105	103	60-120	70-100	Very painful.	Impossible to converse even by shouting.
,,	1927	Quadri-motor 30-passenger transport	75	80	40-95	72-85	Uncomfortable.	Possible with some effort up to 3-4 feet.
Rail.	1934	Railcar	100	90	0-110	(A-10) 95†	Very uncomfortable.	Possible with effort up to 4-5 feet.
,,	1933	Railcar	85	82	0-95	(A-15) 87	Uncomfortable.	Possible with some effort up to 4 feet.
,,	1918	Underground—New York	50	90	0-65	(A-20) 100	Very painful.	Possible by shouting.
,,	1925	U.S. Pullman sleeper...	55	68	0-80	(A-30) 80	Fairly uncomfortable.	Possible with slight effort up to 6 feet.
Land.	1930	Six-cylinder popular passenger car...	40	60	0-70	(A-15) 76	Slightly uncomfortable.	Possible with raised voice up to 10 feet.
,,	1933	Eight-cylinder de luxe passenger car	40	59	0-80	(A-10) 80	Fairly uncomfortable.	Possible with slight effort up to 6 feet.
,,	1933	V-16 passenger car	40	54	0-95	(A-30) 65	Comfortable.	Normal conversation up to 18 feet.
,,	1934	V-12 passenger car	40	56	0-90	(A-25) 70	Comfortable.	Normal conversation up to 12 feet.
Water.	1907	Sail boat	5	30	0-12	A 35	Extremely comfortable.	Conversation in whisper possible up to 50ft.
,,	1928	Motor boat	20	40	0-35	A 50	Very comfortable.	Conversation in low tones possible up to 30ft.
,,	1930	Ocean steamer, first class	32	45	0-35	A 55	Very comfortable.	Conversation in low tones possible up to 30ft.
,,	1929	Ocean motor ship, cabin class ...	23	35	0-30	A 55	Very comfortable.	Conversation in low tones possible up to 30ft.

* All noise level figures are given in decibels above 1 millibar, corrected for the ear sensitivity. Kingsburry weighing network at 60 db. was used.
† Means ambient noise minus reduction due to walls, etc., which have a certain transmission loss.

Owing to the peculiar phenomenon that the sensation of hearing is not proportional to the energy contents of sound but that it is a logarithmic function thereof, sounds which are contributories of a general noise do not add up arithmetically but logarithmically. Consequently in the inverse process of decreasing a given noise the total elimination of one contributory will not accomplish much. In our example, let us suppose that we eliminate the exhaust. The effect upon the total will be very small, a reduction of 2 db., making the total 110 db., to some people a hardly noticeable change. When we talk about this phenomenon even to very intelligent people we meet with scepticism, but a simple experiment is very convincing. Let six or eight persons clap their hands vigorously. Then every six or ten seconds let one person cease clapping. You will be convinced immediately. But let the persons performing this hand-clapping experiment decrease the force of their clapping simultaneously and the decrease in total noise will be very noticeable. The lesson from this simple experiment is that in order to decrease the noise of an aeroplane it is imperative to diminish simultaneously the sound of each contributory source.

1. PROPELLER.

Any body attached to a string or chain and rotated will make some noise; the faster the rotation the more noise will be heard. A propeller can be regarded, very roughly of course, as such a body. Naturally there must be a relation between the peripheral velocity of the blade tip, *i.e.*, tip speed and noise. Davis, in his paper "Noise,"[4] gave a very exhaustive analysis of the subject. With

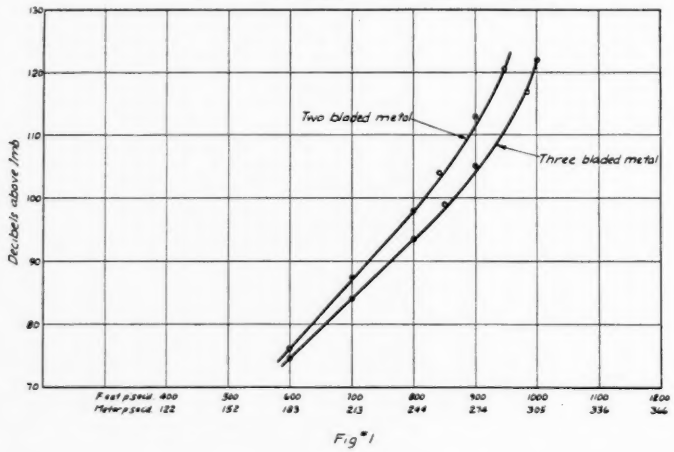


Fig 1

our limited means we confirmed Davis' findings and were able to plot the relation of tip speed to noise (see Fig. 1). We noticed that the noise generated by a propeller follows very approximately the formula

$$\text{Noise in decibels } 10 + 0.11\ V \text{ (two-bladed metal)},$$

where V is the tip speed in feet per seconds. More precise measurements by the N.A.C.A.[5] and Obata[6] seem to confirm all these findings. The above formula seems to be correct up to a speed of about 800 to 850 feet/second, but from repeated tests and observations we are inclined to conclude that this formula is

[4] Journal R. Ae. Soc., Vol. 35, No. 248, page 676.
[5] Ref. 3. Report No. 526.
[6] Obata—Tokio Imperial University, June, 1933.

only true up to this speed, above the noise does not increase as a linear function but apparently follows an exponential law. If the measurements are made with apparatuses corrected for the ear response curve, then due to a great change in the spectrum of sound at speeds above 850 feet/second, this law becomes especially apparent. To keep propeller noise, therefore, at a reasonable level, say 90 db., we will limit ourselves to the use of three-bladed propellers having a tip speed at normal cruising speed of not more than 800 feet/second.

We have observed that the noise of a propeller has unusual directional characteristics. In fact experiments by the N.A.C.A.,[5] Obata,[6] and others prove this statement. We have, therefore, taken most of the published results and plotted them, using a polar system of co-ordinates (Fig. 2), from which it will

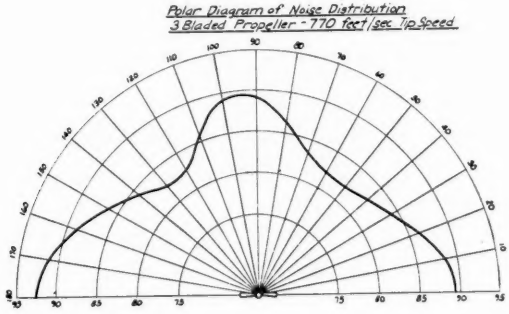


Fig 2

be noted that a maximum noise is in front and in the plane of the propeller. This fact has led in the last few years to the design of preferably even numbered engine aeroplanes such as bi- or quadri-motors. Further, the designers are inclined to move the utility rooms, such as baggage, lavatory, steward service, kitchen, as near to the propeller plane as practicable, reserving for the actual cabin a place in the lowest sound field. We have remarked elsewhere that sound and mechanical vibration are kindred problems. In studying the location of propellers this fact will stand out rather clearly. We noticed that the distance from the tip of an airscrew to the fuselage plays an important rôle, if this distance is very short, say 2 to 3 inches, then due to purely aerodynamic reasons the region in the fuselage right ahead and behind the propeller disc will become very excited and vibrate with amplitudes up to $\frac{1}{4}$in. Apart from the possibility of crystallisation of material at those points this vibration will be felt all over the aeroplane and there might be panels, windows, or other parts which will create by resonance effect a terrific din in the cabin. Experiments with model airscrews and actual aeroplanes give us Fig. 3, from which it can be seen that the minimum distance should be about 12in. (using an 11ft. 6in. propeller). To the question, whether or not an aeroplane is wholly incapable of sound-proofing when this rule is violated, we can say that we have developed a construction which without changing the position of the engine will lessen the noise to a certain extent. In a certain amphibian aeroplane the clearance between the propeller and the fuselage was 2in. The noise in this aeroplane was very high—about 110 db. and of a very particular frequency—quite unlike others we have worked on. The panel under the propeller vibrated with an amplitude of more than $\frac{1}{4}$in. (the limits of our instrument scale). The maximum noise came obviously from this panel and at certain speeds it resembled machine gun fire. Since it was a monocoque structure we simply built a frame about 40in. by 40in. to which, through the intermediary of a rubber strip, we attached the aforementioned

panel. The load was taken through two diagonal wires. Now the panel continued to vibrate, but vibrated noiselessly, and the vibration measured at many points next to this floating panel averaged less than 0.015in. The noise decreased also and dropped to about 100 db.—a reduction which could not be accomplished by any soundproofing material.

2. EXHAUST.

Who has not heard the statement that what is needed to get a quiet aeroplane is only a good muffler; we had at least thirty so-called silencers submitted to us, but without discussing the merits of any one we can state that a silencer which attenuates the noise far below that of the propeller—say to 70 db.—is not worth putting on since the total effect upon the noise in the cabin would be negligible. To prove this definitely we conducted an experiment using an excellent turbo muffler on a bi-motor aeroplane. One engine was equipped with a muffler, the other had conventional stacks. The results of this test are summarised in Fig. 4. The gain, if any, was negligible. By changing, however, to a three-

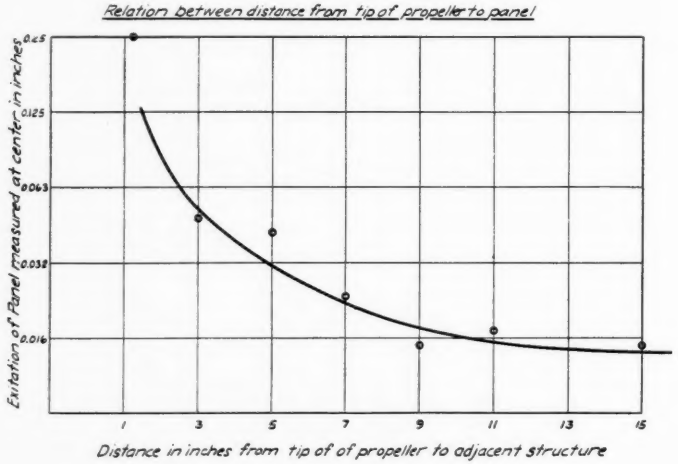
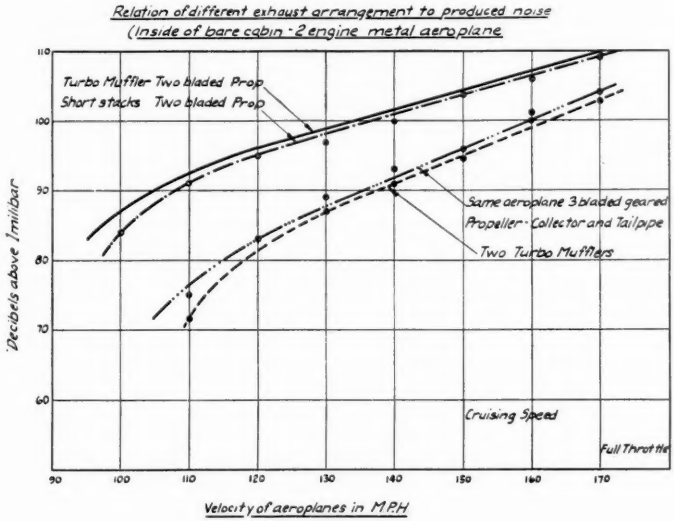


Fig 3

bladed geared propeller and simultaneously putting a collector and tail pipe on the aeroplane a great deal of noise was eliminated. The U.S. Bureau of Standards[7] has accomplished a great deal by testing a series of mufflers in the laboratory. It came to exactly the same conclusion. Let us not forget, however, that sound decreases approximately in inverse proportion to the square of the distance. Hence, exhaust pipes should be placed on the far side of the nacelle or above the wing, briefly, as far away from the cabin as possible. Wings, nacelles, and other structural parts form an excellent barrier to sound. Substantiating the above statement we had a case of a bi-motor aeroplane with six-cylinder in-line engines where the right engine exhausted inboard, the left outboard. With the left engine at 75 per cent. the noise in the treated cabin was 72 db., with the right engine at the same power output it was 76. With both engines at 75 per cent. we had about 77 to 79 db. After the right engine had been changed to have its exhaust on the outboard side the total noise level dropped to 73 db., or 2 db. less than theoretically expected, as $72+72=75$ db. Since

[7] Ref. 4. U.S. Air Commerce Bulletin, Vol. 4, No. 12, December, 1932.

we made extremely careful measurement and repeated them several times with consistent results, the 2 db. extra gain can be attributed only to the (*a*) removal of a local noise source 24in. farther, and (*b*) the elimination of the local vibratory excitation. In fact, in the former case the gases leaving the stacks at a speed quite in excess of the speed of the aeroplane can strike the fuselage and thus create a concentrated sound and vibratory field. As a conclusion it may be mentioned that by careful design, having the above facts in mind, an attenuation up to 90 db. of the exhaust can be expected. The problem of exhaust collectors seems to be under perfect control on radial air-cooled engines. On liquid-cooled engines, especially of the V type with outboard exhaust valves such as the Rolls-Royce, Hispano and Curtiss, a great difficulty seems to present itself in making the collectors, which form straight pipes with very short elbows, to stand up under the combined stress of heat, pressure and vibration. It has been observed



Fig°4

that the life of such exhaust collectors is extremely short. In our opinion, it should be the duty of the engine builder to look into this problem very seriously as it offers a fertile field for major improvements. To date, at least on the continent, we did not find a design which would meet our full approval.

3. Engine Clatter.

Acoustical studies, using proper bandpass filters, reveal that the noise made by the engine as a machine, viz., gear, valve tappet, supercharger, carburettor noises, are of a magnitude of 75 to 85 db., or far below that of propeller and exhaust, and can be disregarded at least for the time being. However, since a noise always points out an inefficiency, the aeronautical comfort engineer and, as a matter of fact, the aeroplane designer will welcome all attempts which will lead to the quieting of prime movers.

We must again point out the close relationship between vibration and noise, because no matter how quiet the engine may be it can become a very serious source of secondary noise in the cabin if the attachment of the engine to the structure is not made very carefully. The most carefully made and balanced prime mover will have some unbalanced parts, and no matter how slight the

vibration might be if the engine is not properly attached to the structure some secondary vibrations will be generated in the fuselage, many of them creating potential sources of much unwanted noise. Hence, a discontinuity between the engine and the structure becomes a very important part of soundproofing technique.

I have been a strong advocate of elastic suspensions of engines, having designed some as early as 1927 (centre engine Ford tri-motor). It was only in 1931 that the basic theory of elastic engine mounts was published,[8] and in 1932 it was discovered in connection with another problem[9] that elastic mountings loaded in shear offer even higher attenuation values than we had reason to expect on the basis of result of ordinary mechanical analysis. Studying the theory of elasticity and damping, it is possible to prove this statement by the judicious application of Hooke's law. Since, however, certain necessary assumptions in such an analysis might appear far-fetched, the following experiment will convince any sceptic. Let us take identical pieces of rubber, apply an equal load to one in shear and to the other in compression. The two samples are then subjected to an identical vibratory motion and the temperature of the rubber measured. The temperature gradient of the piece loaded in shear will be found to be about 30 to 40 per cent. higher than that of the other sample. Since the amount of heat generated can surely be regarded as an index of energy dissipation a more elaborate proof is surely not necessary.

In practice there are two accepted ways of constructing elastic engine mounts. The flexible element can be located either on the mounting ring or at the clevis pin. The latter construction has been used successfully on the Douglas DC-2, but it necessitates rather elaborate fittings. Also since there only three or four points to locate the fittings, the designer is often cramped for space—the fittings, due to the distance from the C.G. of the engine become rather large. On the Wibault 670 and the latest transport aeroplanes in the U.S.A. the engine ring mounting was chosen, and it seems that this solution will soon become classical. It is very often imagined that the calculation of such a flexible mount is complicated, also that the rubber is overloaded and the design not safe. The following calculation taken from an actual design (Curtiss Condor XT-32—9-cyl. 750 h.p. Wright Cyclone engine) show the simplicity of such an analysis. Figs. 5 and 6 show the details of the installation.

Analysis of Forces Acting on Shear Type Mountings.[10] For a 9-cylinder 750 h.p. Radial Engine.

The calculations are based on using shear type mountings (see Fig. 6) for the Wright Cyclone engine, SGR-1820-F2, with the mountings arranged as shown on Fig. 5.

The forces acting on the mountings can be split up into four components:—(*a*) Vertical load due to gravity, (*b*) due to the static overhang moment, (*c*) due to engine torque and, finally, (*d*) due to airscrew thrust. Each of these forces can be resolved into one component, causing axial or shear stress on the mountings and another causing direct or radial stress. Table II shows the components and the resultants.

(*a*) Vertical Shear.

In order to find the actual load carried by each mounting due to vertical shear we assume that the resulting deflection of the engine due to this component coincides with the vertical axis. This assumption is true if the mountings are placed symmetrically on the mounting ring.

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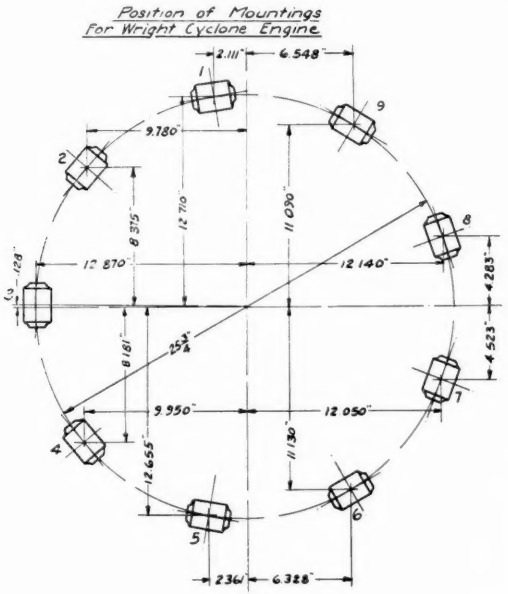
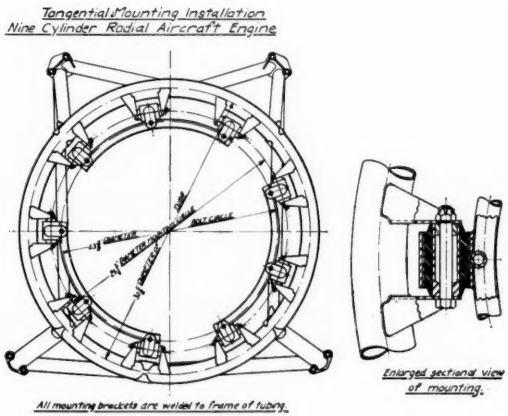
[8] Ref. 5. "A Study of Instrument Board Vibration," S.A.E., October, 1931, p. 263.
[9] "Vibration of Instrument Board and Aeroplane Structure," S.A.E., September, 1932, both papers by the Author.
[10] Shear type mountings are manufactured by the Lord Mfg. Co. in Erie, Pa. (U.S.A.).

Since the mountings are firmly attached to the engine, we reason that all of the mountings must deflect equally under the vertical shear load, and the load carried by each mounting is dependent upon the specific deflection of the mounting. In case cited the mounting is about 6.5 times as stiff when deflected radially



Fig°5


Tangential Mounting Installation
Nine Cylinder Radial Aircraft Engine
All mounting brackets are welded to frame of tubing.
Enlarged sectional view
of mounting.

Fig°6

than when deflected axially. Therefore, for a given deflection the load carried by sitting in a horizontal position is 6.5 times that carried by a mounting in a vertical position.

The relative location of the mountings is shown in Fig. 5.

Denoting :—

F_v = vertical shear force per mounting (pounds).
F_a = axial component of F_v (pounds).
F_r = radial component of F_v (pounds).
d_a = axial component of d_v (inches).
d_v = total vertical deflection per mounting (inches).
d_r = radial component of d_v (inches).
E = coefficient of elasticity (lbs. per inch).
a = angle of axis of mounting with the horizontal (degrees).

Then, since

$$F = Ed,$$
$$F_a = Ed_a, \text{ and}$$
$$F_v = 6.5\, Ed_a,$$

and

$$d_a = \sin a d_v, \text{ and}$$
$$d_r = \cos a d_v,$$

also

$$F_v^2 = F_a^2 + F_r^2.$$

The sum of all the values of F_v for each mounting is the weight of the engine, propeller and accessories; in this case 1,670lbs.

We know from deflection tests that the approximate value of E for the mounting is 5,100lbs. per inch. Then by trial and error assumption of values for d_v we get values for F_a, F_r and F_v as given in the Table II.

(*b*) STATIC OVERHANG MOMENT.

From data furnished us by the engine builder we know that the weight of the engine and accessories is 1,420lbs., and the centre of gravity of the engine is 8 inches ahead of the plane of the mountings. The propeller weighs 250 pounds and is located 26 inches ahead of the plane of the mountings. Therefore, the moment will be

$$(8 \times 1{,}420) + (26 \times 250) = 17{,}860\text{lbs. ins.}$$

The couple tends to turn the engine about a horizontal line coinciding with the centre of the system. Therefore each mounting will be deflected radially a varying amount proportional to the distance from the neutral axis. The force on each mounting will be a function of the deflection.

Let X = the force on a mounting whose distance from the centre equals the radius of the mounting circle, or, in our case, 12.875in. Then for point

1. $(12.71/12.875) \times 12.71 \times X = 11.66\ X$
2. $(8.375/12.875) \times 8.375 \times X = 5.447\ X$
3. $(0.128/12.875) \times 0.128 \times X = 0.0013\ X$
4. $(8.181/12.875) \times 8.181 \times X = 5.20\ X$
5. $(12.655/12.875) \times 12.655 \times X = 12.435\ X$
6. $(11.13/12.875) \times 11.13 \times X = 9.615\ X$
7. $(4.523/12.875) \times 4.523 \times X = 1.589\ X$
8. $(4.283/12.875) \times 4.283 \times X = 1.545\ X$
9. $(11.09/12.875) \times 11.09 \times X = 9.560\ X$

$$\text{Total} = 57.052\ X$$

$$57.052\ X = 17{,}860$$

$$X = 313.$$

The load due to overhang on point 1 is then equal to

$$(12.71/12.875) \times 313, \text{ or } 309\text{lbs.}$$

See Table II giving the respective loads for each point.

TABLE II.

Key :—F Forward.
B Backward.

Key :—Axial loadings, A Anti-clockwise.
C Clockwise.

SUMMARY :—

FORCES ACTING ON MOUNTINGS IN CURTISS WRIGHT CONDOR INSTALLATION.

1	2	3	4	5	6	7	8	9	10	11	12
Pt.	Horiz. Distance from C.L. + Left, − Right	Vert. Distance from C.L. + Above, − Below	Vertical Shear F_v	Load F_a	F_r	Moment Reaction lbs. per Mount Radial	Torque Reaction lbs. per Mount Axial	Prop. Thrust lbs. per Mount Radial	Resultant Axial Load 5+8	Resultant Fore & Aft 7+9	Resultant Radial Load $\sqrt{(6^2+11^2)}$
1	+2.111″	+12.71	282	A 5	281	F 309	A 304	F 133	309	F 443	525
2	+9.780″	+8.375	189	A 33	186	F 204	A 304	F 133	337	F 337	385
3	+12.870″	+0.128	44	A 44	0	F 3.1	A 304	F 133	348	F 136.1	136.1
4	+9.95″	−8.181	184	A 34	181	F 199	A 304	F 133	338	B 66	193
5	+2.361″	−12.655	281	A 8	280	F 308	A 304	F 133	312	B 175	330
6	−6.328″	−11.13	249	C 21.5	248	B 270	A 304	F 133	282	B 137	283
7	−12.05″	−4.523	101	C 41	100	B 110	A 304	F 133	263	F 23	103
8	−12.14″	+4.283	96	C 41	95	F 104	A 304	F 133	263	F 237	247
9	−6.548″	+11.09	246	C 22	245	F 270	A 304	F 133	282	F 403	472

(*c*) ENGINE TORQUE.

$$T = (63{,}000 \times \text{h.p.})/\text{r.p.m. of propeller.}$$

In our example we have

$$\text{h.p.} = 750.$$
$$\text{r.p.m. of engine} = 1{,}950.$$
$$\text{Gear ratio} = 16.11.$$

The torque then is

$$(63{,}000 \times 750 \times 16)/(1{,}950 \times 11) \text{ or } 35{,}250 \text{ (inch/lbs.)}.$$

The radius of the mounting circle is 12.875in. The load per mounting is therefore

$$35{,}250/(9 \times 12.875) = 304\text{lbs.}$$

(*d*) PROPELLER THRUST.

This load for the airscrew employed was approximately 1,200lbs. and is taken equally by all the mountings, and the load per mounting will be

$$1{,}200/9 = 133\text{lbs.}$$

CONCLUSIONS.

It will be noted that the maximum radial stress occurs on mounting 1. The total load is 525lbs., making a load per square inch of projected area of 262.5lbs. We would consider this a safe loading. In general, the arrangement used for this installation does not produce excessive direct or radial loadings on the mountings.

The axial loading is not uniform for all the mountings. The load due to torque represents the average axial loadings, and it may be presumed that the choice of mountings for other engines, using the same general arrangement, can be based on proportioning the mounting stiffness to the direct ratio of torque loading.

On in-line engines the aeroplane designer should be very careful to inquire from the engine builder whether the crankcase is stiff enough to be self-supporting or whether it needs the engine bearer to act as a stiffener. Should the latter be the case then it is wise to use the clevis type mountings.

There was recently an opportunity to test the importance of resilient fittings. On one of the French bi-motor aeroplanes the left engine was mounted in the regular way, the right one through shear type rubber fittings. The difference of noise level in the cabin when running on either engine, after repeated tests and extending such experiments over different air and motor speeds, was consistently 2 to 3 db. lower, proving beyond any doubt that prevention of sound reaching the cabin by eliminating the possibility of solid conduction is quite important. Similarly there should be discontinuity in the design construction of the exhaust pipe.

AIRBORNE SOUNDS.

Any noise which originates in the cabin proper, such as drumming of bulkheads, buzzing of hand-baggage racks, etc., is called an airborne sound. Elastic suspension of prime movers will do a lot in diminishing the possibility of these sounds, but, nevertheless, additional precautions are necessary in order to make a cabin acoustically acceptable.

If any elastic body or any elastic system is suddenly subjected to external forces, or if continuously applied forces suddenly change or are altogether removed, it will vibrate because the elastic forces of the system will no longer be in equilibrium with the loading. The aeroplane structure is certainly one of the most elastic structures known and the loads, aerodynamic and others, do change constantly during flight. Hence any structural part which happens to be in the cabin will vibrate and consequently be a source of sound. A logically constructed soundproof aeroplane cabin must, therefore, have as few stress taking structural

parts as possible. For example, many designers take all secondary shear stresses through the floor, a construction that is light and simple. From the passenger comfort point of view this is a poor design because the floor will vibrate and secondarily act as a sounding board. By taking the load through a series of stringers, or traverses, and building the floor of small panels, say 18 × 4oin. interlocked with each other with rubber or cork gaskets and attaching this assembly by means of felt or rubber pads to the traverses, an acoustically irreproachable construction is obtained.

Inter-cabin bulkheads are another part of the structure so easily used for taking stresses. But it is equally easy to build cabins free from internal bracing and depend on full monocoque structures, or on self-supporting U or Z-shaped rings, such as seen in the Douglas, Wibault, and other modern designs. If the designer must take braces, struts, spares, etc., through the cabin, then he must sacrifice at least 1½ to 2in. to either side of such an obstruction and some additional weight for extra insulation.

The stiffest material of an aeroplane is undoubtedly the glass used for windows. If this glass is attached to a metal frame it will act like a loudspeaker diaphragm and transmit into the cabin a great many high frequency sounds, forming a highly excited sound field right next to the passenger's ear. The accepted method of mounting glass is in a channel of extruded rubber, the whole unit being then

Cross-section through proper window mounting.
(U.S. Patent #1991832)

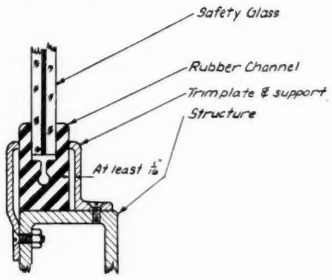


Fig 7

clamped solidly, on the contention that the rubber gasket will serve the dual purpose of keeping the assembly water- and air-tight and acting as a vibration absorber. Rubber and, as a matter of fact, any elastic material can act as a proper means of discontinuity only if it can displace itself, which in the construction cited above is not the case. By mounting the window as shown in Fig. 7, however, permitting the rubber to contract and expand, proper vibratory attenuation is obtained without sacrificing the extremely important consideration of imperviousness to air and water.

A great deal of noise will be generated if the cabin trim is so attached as to have the possibility of rattling; that the large unsupported panels, such as wainscoting, inter-cabin bulkheads, etc., must be designed in such a way as to prevent them from generating sound. It is impossible to list all the remedies, sleights of hand, tricks, etc., which can be used to accomplish such an elimination of unwanted sounds. In general, the ingenuity of the cabin designer will be taxed to the utmost to provide the appropriate treatment.

It is worth while to mention that all " accessories " of a large cabin, such as ashtrays, drinking glasses, mirrors, fire extinguishers, seat belts, etc., must be attached to the structure in such a way as to make it impossible for them to get into a vibratory state. The maintenance crew should periodically check the

attachments and the slightest play in such parts should be removed. We should not forget that the faintest buzz in a truly quiet aeroplane is highly distracting and annoying to the passengers. Summarising, it may be said that the noise due to airborne sounds can be brought down by proper design and strict maintenance to less than 65 db.

VENTILATING NOISES.

We set out to discuss the whole problem of air travel comfort, and while it will be quite difficult, owing to lack of space, to go into a detailed discussion of all items contributing to comfort, the fact that we must discuss ventilating noises forces us to discuss ventilating systems in general.

We know now that a large number of cases of air sickness in the older types of aeroplanes was caused by lack of fresh air. Many aeroplanes of 1927 did not have provisions for metered introduction and extraction of air and the designer depended on natural leaks in the cabin for the supply of air. Yet it is fairly easy to find out how much air a person requires if he is to be comfortable and well. About 300 cc. of air (tidal capacity) is normally passed in and out of the chest at each respiration. By deeply inhaling an extra 1,500 to 2,000 cc. can be inhaled into the lungs (complemental air), and similarly about 1,500 cc. can be expelled in addition to the tidal. This is called by medical men supplemental air. The sum of the three, viz., $300+2,000+1,500=3.8$ litres, has been termed vital capacity and represents the strictest minimum of air at sea level consistent with a feeling of well being. Since under normal conditions at sea level we respire sixteen times a minute, the minimum amount of air per person at sea level per minute will be $3,800\times 16=60,800$ cc. of air, or about 60 litres per minute, or about 2.1 cu. ft./min. But aeroplanes are rarely at sea level and since the amount of oxygen is much less at altitudes, a ventilating system should provide sufficient air under all conditions and therefore a much larger capacity is necessary. We examined the literature on the subject and found that public halls require 5 cu. ft. per person per minute, schools 10 cu. ft./min., while progressive railroads prescribe 15 cu. ft./min. On one of our aeroplanes we dimensioned our ducts so as to provide 20 cu. ft. of air per minute, and while this amount seemed satisfactory at first, during the summer some persons began to complain. When the Douglas DC-1 was under test we experimented with varying amounts up to 60 cu. ft./min./person, finally establishing that 30 cu. ft. (850 litres) is the minimum normally, while on very hot days a ventilating system capable of giving the passengers up to 60 cu. ft. will be ideal under all circumstances. Having established the amount of air necessary we must find a scheme for introducing it noiselessly as sound is most readily transmitted through openings, a fact so obvious that it does not require expatiation. It is not generally known, however, that a small crack will transmit a disproportional amount of noise. The reason for this fact is, first, that the sensation level of sound is proportional to the logarithm of intensity, and second, that a sound which passes through a small opening is diffracted so much as to spread out in all directions from this orifice, as though the small opening were itself a source of sound.

In order to make the first consideration clear, let us assume that we have a perfectly sound-insulated aeroplane in which the level at a certain flying speed is 110 decibels outside and 70 db. in the cabin. Considering the fact that our passengers require some 600 cu. ft. of air per minute we find also that to provide such an amount an opening 10in. long is necessary. Unfortunately, we see that due to the phenomenon of diffraction the noise of the cabin increased to the noise outside, *i.e.*, 110 db. In order to remedy the situation we reduce the opening ten times or to one inch. Thus the energy transmitted through that opening will be decreased tenfold, which simply means that the noise transmitted will drop but 10 db. or the cabin will still roar with a noise of 100 db. We go one step further and reduce the opening again ten times, or to a width of but 0.1in. Repeating the same reasoning the noise will drop another 10 db. and our cabin is

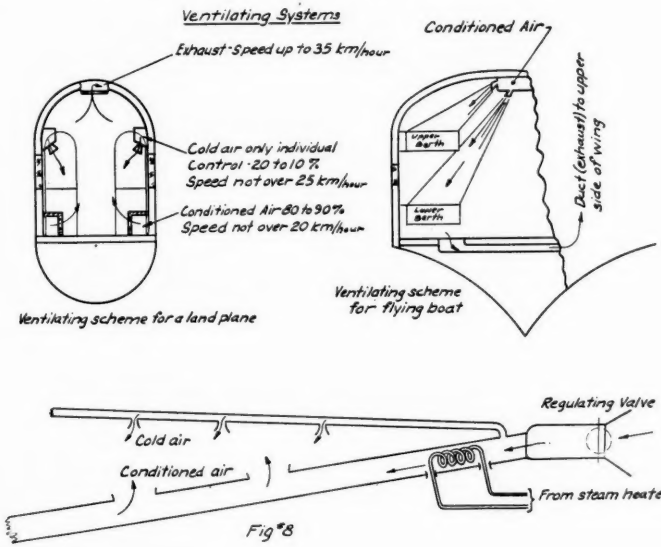
still noisy, showing, instead of 70 db., 90; we would have to close down our imaginary opening to 1/10,000 of its original size to have the cabin at 70 db. It would appear, therefore, that the fact that human beings require a considerable amount of air to be comfortable will preclude the possibility of a quiet cabin as a compromise is obviously impossible. But theatres, churches, assembly halls, must fulfill the same requirement—and what do we find? The architects provide in such structures ventilating openings of suitable sizes, but instead of bringing them out directly into the rooms an acoustical capacity is used instead. A duct is such a capacity. Large ducts suitably treated will attenuate the noise and at the same time bring in the quantity of air necessary. We shall, therefore, bring in the air through a duct and such an acoustical capacity can be dimensioned as soon as we know the velocity of air consistent with comfort. Repeated experiments have shown that 15 to 20 km.h. is about the maximum speed of air which will not create draughts. Therefore, per passenger, the cross section of an opening will be about

$$(800 \times 1{,}000 \times 60)/(20 \times 1{,}000 \times 100) = 24 \text{ cm.}^2 \text{ or } 3.7 \text{ sq. in.}$$

Assuming a 20-passenger cabin with a double duct then the cross section would be

$$10 \{ (800 \times 1{,}000 \times 60)/(20 \times 1{,}000 \times 100) \} = 240 \text{ cm.}^2 \text{ or } 37 \text{ sq. in.}$$

As we see, a perfectly realisable dimension. In order to get the velocity of 20 km.h. certain experiments will be necessary as, for the time being, the losses at the point where the air is taken into the duct cannot be evaluated.



There are many possibilities as to the location of a ventilating duct, a scheme generally used on landplanes and on large flying boats is shown on Fig. 8. Both schemes allow a heating scheme to be incorporated with the ventilating system, a design which effects a considerable saving in weight. The air is taken in preferably at a point where there is least noise, such as at the nose of the aeroplane. The main tube has a by-pass conveniently located so as to permit the air to be heated. On the landplane scheme, it will be noted, there is an upper tube serving as means of individual ventilation. This upper tube always supplies cold air. About 10 per cent. of the total air may be by-passed by the

upper tube. The velocity can be slightly higher, as in the lower main duct but 25 km./m. should be considered as a maximum. Both upper and lower outlets are best arranged in a number corresponding to the number of passengers. The designer can naturally use his own ingenuity as to the best arrangements. The used air must be exhausted and again an acoustical capacity is necessary to accomplish this quietly. Generally one opening per three to five passengers is sufficient, the velocity in the exhaust duct can be 35 to 40 km. The ducts must be made of non-reverberant material lined with absorbent goods. Various schemes are possible, of course. By far the most elegant solution is the one shown on Fig. 9, which consists of structural parts made of half hard aluminium

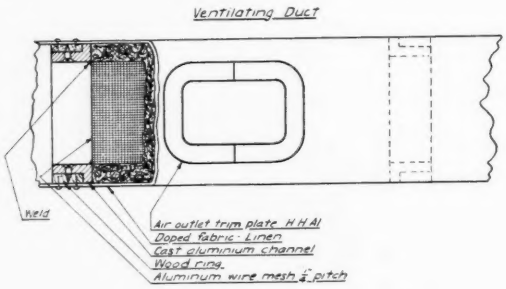


Fig 9

spaced about 3 to 4 feet apart to which an aluminium wire mesh has been welded, around which a $\frac{1}{4}$ to $\frac{1}{2}$in. felt is sewn, this whole assembly wrapped in aeroplane fabric and doped.

With all these precautions it may be found that some ventilating systems still remain noisy—a swish or whistle may be perceptible. Should this be the case a frequency analysis will show the offending predominant noise and the designer can, as a last resort, turn to acoustical filters.[11]

A metered ventilating system as described will function properly only if there are no leaks in the cabin. Thus hand in hand with proper ventilating schemes goes the design of doors and gaskets. Bearing in mind diffraction phenomena, a properly designed door is extremely important in a quiet aeroplane. The door of an aeroplane is relatively much stiffer than the fuselage. Thus, since the fuselage is subject to greater deformation than the door it may and has happened that a door perfectly tight on the ground shows $\frac{1}{4}$in. clearance during flight, upsetting the ventilating system and not only admitting the outside roar, but creating its own whistling sound. The door should, therefore, be so designed as to be tight at all times. A quadruple lock, as shown on Fig. 10, is a very good expedient. On the Breguet " Fulgur " the hinges were so built as to give the door a parallel motion in relation to the sill, thus creating an even pressure on the gasket. A pneumatic gasket has been successfully used, expanding as soon as the aeroplane has reached a certain altitude. Many schemes are again possible, and while details will have to be adapted to the given structure the designer should not be tempted to minimise the importance of a perfect closure at all times. Gaskets should be periodically inspected and renewed at least every three months.

Suppose we have designed an aeroplane following all these recommendations, what noise level can we expect? The propeller, a three-bladed one, turning not fast, will contribute about 86 to 90 db. The exhaust collector with its well shielded tail pipe will attenuate the engine to 86 to 90 db. Since in 1936, struts, wires, and other protuberances are definitely outmoded, we can assume that there

[11] Ref. 6. Steward and Lindsay, " Acoustics " (The Van Nostrand Company).

will be very little noise from aerodynamic sources, say 65 to 70 db. Logical designs of engine mounts, floors, windows, properly secured trim, will have diminished airborne noises to 60 to 65 db. Finally, our ventilating system made with care, using soundproofed ducts and filters, will contribute but 58 to 62 db. The sum will be 86 to 92 db. Recalling our original enumeration which gave 112 db. we see that for all our effort we gained but 18 to 24 db. In the best possible case our aeroplane is still very noisy, showing about 90 db., or at least 15 db. too much to be termed a comfortable vehicle. To gain the remaining 15, or better still 20 db., we have to look seriously into sound insulation and sound absorption.

Sound Insulation and Absorption.

It is highly unfortunate that fundamentals of acoustics were not studied by aeronautical designers many years ago. Even to-day many prominent engineers depend on the information and advice of sales engineers who have a particular material to sell. The literature of nearly every concern which sells sound

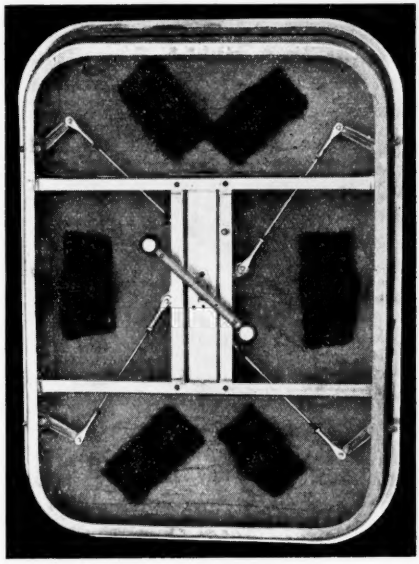


Fig. 10.

insulating material is filled with proposed schemes of construction for sound insulation. Some of these schemes are meritorious, some very misleading and of doubtful value. Booklets on sound insulating materials are filled with mysterious figures, diagrams and charts explaining everything but plausible theories confirmed by exact measurements. One of the principal fallacies inherent in many sound insulating schemes is the erroneous assumption that materials and methods which are effective for heat insulation are also effective for sound insulation.

It must be pointed out that heat and sound insulation are entirely separate problems, governed by very different physical laws; and while it may happen that a good heat insulator is also a good barrier to sound, no general conclusion can be reached that every heat insulator is also a sound insulator. Two principles are used in the control of unwanted sounds, (*a*) sound insulation by means of rigid, more or less, homogeneous panels or partitions, (*b*) sound absorption by means

of porous flexible materials. In the aeroplane, the proper combination of the two schemes seems to be the only one which is conductive to desirable results.[12]

A rigid partition, if placed in a sound field, will be forced into vibration by the impacts of the sound waves against it. The wall becomes thus a secondary source of sound and will radiate a certain amount of sound to the space adjacent to the opposite side of the wall. If this reasoning is correct, then, according to Knudsen,[12] the insulation value of such a wall will depend primarily upon the mass or inertia of the wall, the stiffness of the wall, and the internal resistance or damping coefficient of the material. But every partition, and, as a matter of fact, any body, will have certain natural modes of vibration. Thus, if it were not for the internal damping of such a material, the transfer of acoustical energy at resonance to the opposite side of the panel would be quite considerable. Fortunately, the damping of most materials is fairly high so that these resonant frequencies are generally flattened out. Nevertheless, rigid partitions will show a lower insulating value at some frequencies than at others. In other words, if we want to specify a rigid partition for an aeroplane, we must know not only how much of the noise we want to prevent from reaching the cabin, but also what type or what frequencies we desire to exclude.

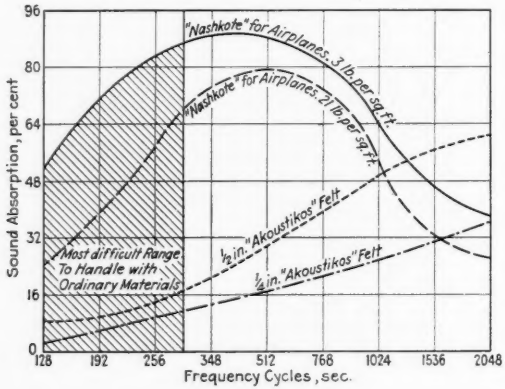


FIG. 11.

The mass of a wall offers a reaction to the sound wave similar to the magnetic reaction of a self-inductance in an electrical circuit. On this basis, the mass of a partition ought to be the principal factor in determining the insulating value of the partition. In both the mechanical and electrical equivalent, this reaction increases with frequency. Exhaustive laboratory tests conducted by Knudsen,[13] Davis,[14] Mayer,[15] the Bureau of Standards, seem to prove quite conclusively that this outlined theory is correct, and that the insulating value of a rigid partition is approximately proportional to the logarithm of the mass per unit area of the panel in question. Fig. 11 shows the relation, taken as an average, of results at frequencies of 128 to 2,048 cycles. Thus, the transmission loss of a rigid panel which weighs 1lb. per sq. ft. is 22 decibels, at 10lb. per sq. ft. the value increases

[12] Ref. 7. V. O. Knudsen, "Measurements and Calculation of Sound Insulation," Journal Acoustical Society, Vol. 2, No. 1, July, 1932.

[13] Ref. 8. V. O. Knudsen, "Measurements and Calculation of Sound Insulation," Journal Acoustical Society, Vol. 2, No. 1, July, 1932.

[14] T. Mayer and F. Knopfel, "Die Directive Wirkung des Schalles," Physicalische Annalen Leipzig, 1932.

[15] "Sound-proofing of Airplane Cabins," Chrisler and Snyder, Research Paper No. 63 Bureau of Standards.

to 37 decibels, etc. This relation is somewhat discouraging from the aeronautical standpoint, but is very enlightening to those who believe in magic sound insulators.

Recalling our imaginary aeroplane of preceding pages, we see that by careful design we were able to attenuate noise near the source to 90 decibels. Fair acoustical comfort starts at about 75 decibels; comfort at 70 decibels. Thus, we would need a cabin material giving us, in the first case, a transmission loss of 15 decibels, and in the second case 25 decibels. The weights would be about 0.75lb. per sq. ft., and 1.6lb. per sq. ft. A fair sized cabin measuring $20 \times 6 \times 6$ft., will have a total approximate area of 552 sq. ft. The amount of weight, therefore, necessary to get fair comfort would amount to 415lb. For real comfort, however, 885lb. would be necessary. We realise, then, that because of the slow increase in insulation value as compared with increasing mass, this method of soundproofing will not be suitable as an acoustical treatment of aeroplanes.

The insulation of sound by porous flexible materials, such as hair felt, Kapok sheet, or blankets, mineral wools, etc., is accomplished, according to Knudsen, by losses of vibratory energy within the material. The transmitted sound wave is attenuated by viscous losses within the capillary pores of the material and by the vibration of the component parts of the material. It would be expected from the nature of those internal losses of sound energy within the pores that the fractional loss through, say, the first inch, will be the same as through the sound, etc.[16] In other words, if the sound energy be reduced tenfold, in the passage through the first inch, it would be reduced 100 times after passing through the second inch, etc. Measurements by Davis and Litter, as well as our experiments, prove this assumption, and we may say that the logarithm of the energy reduction or the attenuation in decibels is roughly proportional to the thickness of the material. But unfortunately, porous materials, if used by themselves, do not provide a very large amount of insulation unless the blanket be very thick. We cannot insulate an aeroplane by covering it with a blanket of, say, Kapok, or Kapok sheets, because the thickness necessary to give an attenuation of about 20 decibels would become 5½in. or thereabouts. The most effective way of obtaining high insulating values is properly to combine the two known principles of sound insulation, *i.e.*, by inertial losses in rigid partitions and viscous losses in porous flexible materials. One of the most effective ways of obtaining a high degree of insulation is to suspend the porous flexible material in an air space between two rigid partitions. Tests made by the Bureau of Standards and in our laboratory on many combination panels show that it is possible to get insulating values as high as 24 decibels for a weight of 0.3lb. per sq. ft. It will be thought, therefore, that we will proceed now to describe our magic panel. You will be disappointed, because each panel tested shows a different insulating value for different frequency bands. Thus, unless a frequency analysis of an aeroplane is available, no definite panel can be recommended. Whenever we treat an aeroplane, we fly it first without any acoustical treatment, and determine the distribution of noise in magnitude and frequency. Then, and only then can we recommend the necessary insulating materials. The materials thus chosen will then give maximum insulation with minimum weight, because of their proper location and frequency response.

Let us assume that in the front part of an aeroplane the analysis shows that 90 decibels at 250 cycles and 70 at 512 is the maximum disturbance; in the rear of the ship, 80 decibels at 512 cycles is the maximum; and at 250 cycles per sec., we have 75 decibels. Naturally, in order to get a good balanced spectrum, we will treat the front in such a way as to get maximum attenuation at 250 cycles, and in the rear the treatment will concentrate on the elimination of the 512 cycles per sec. disturbance. It would be wasting weight if the front and rear were treated alike. To make soundproofing complete, it is also necessary to treat the inside of the cabin in such a way as to prevent any residual noises from building

[16] Ref. 9. Crandall, " Theory of Vibrating Systems and Sound," D. Van Nostrand Company.

up by reverberation. Theoretically, if there were no absorption in a room, the noise level would reach the same intensity inside the cabin as it has outside, irrespective of the transmission loss of the walls. It follows that reverberation control is equally important.

In working out the proper absorption scheme of the inside of the cabin, we have again to be very careful to use such materials as will absorb those frequencies which are most predominant in that particular aeroplane. Unfortunately, the greatest amount of noise in most aeroplanes is in the lower bands of the spectrum. That means frequencies from 50 to 350 cycles were most predominant in aeroplanes we had the opportunity to work on. Most acoustical absorbers known heretofore have a low absorption coefficient at these frequencies. There are practically no lightweight materials known which would efficiently absorb frequencies in the lower band of the spectrum. Through the joint efforts of John Parkinson, of the Johns-Manville Co.,[17] and our staff, we were able to develop and patent a combination of two materials which weigh very little and show a remarkable sound absorption at the low frequencies.

Our construction has another advantage, in that it employs an inexpensive fabric or any material which can be stretched. This material gives an exposed continuous surface which is smooth and strong and easily decorated. It can be painted with fire-resisting paint and can be washed whenever soiled. Behind this stretched cloth we cement a special felt, so that the felt is completely concealed and cannot be seen from within the cabin.

The important feature of this construction lies in the fact that we have a light membrane in tension which, combined with a sound absorbent damping material attached to the back, can be readily vibrated by the sound waves. Neither material alone will give the desired efficiency. Fig. 12 shows how little efficiency thin

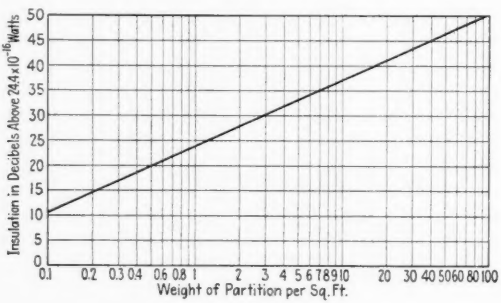


FIG. 12.

felt possesses at the low frequencies in which we are interested. The membrane by itself will have a certain absorption at its resonant frequency, and this absorption will be sharply critical with frequency. The application of the special felt, we have found, causes the absorption to be spread well across the frequency range, due partly to the damping effect of the felt fibres and partly to the added mass reactance and what might be called an inertance. It will be apparent that for full effectiveness this construction should be spaced from the wall or surface behind. Our experiments indicate that the greater this spacing the more effective the low frequency absorption. Our experiments likewise show that the heavier the felt the more effective the low frequency absorption. For practical purposes, $\frac{1}{4}$ to $\frac{1}{2}$in. felt will be satisfactory. The weight of this construction varies from 0.2lb. per sq. ft. to 0.4lb. per sq. ft.

[17] Ref. 10. U.S. Patent 2,029,441.

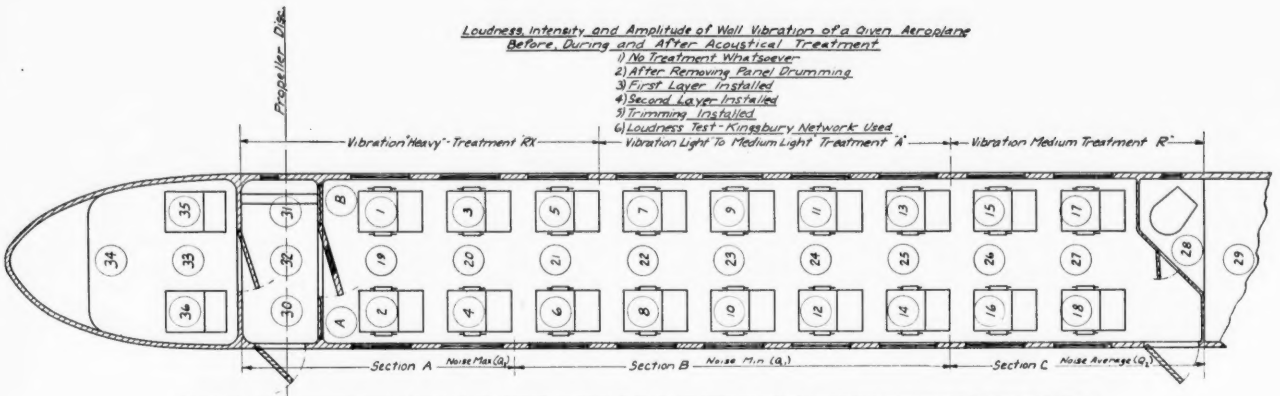
In order to determine the amount of absorption necessary to get a specified noise reduction factor in decibels, it is most convenient to determine the ratio of the intensity of the noise outside the cabin to the intensity of the noise which is transmitted into the room. If we denote intensity outside by I_1 and the intensity which is transmitted into the cabin by I_2 then the ratio I_1/I_2 will give us the reduction of the noise accomplished by the passage of sound waves through the surrounding panels, walls, ceiling, floor, etc. But the intensity of a noise transmitted into a room is equal to the rate of flow of sound into the room, divided by the total absorption of the room. Or denoting by T the total transmittance (sum of the transmittances of the different walls, etc.), and by A the total absorption, then the true noise reduction factor in decibels will be $10 \log_{10} (\Sigma A/\Sigma T)$. Both the transmittance of our walls, etc., and the absorption coefficients of materials used inside the cabin, can be obtained from laboratory tests. This formula will, as will be shown, reveal whether it is more economical to increase the noise reduction factor of a cabin by altering the construction of the walls, etc., or by adding absorption.

We shall now take as an example a given aeroplane and describe a series of tests with it and show the actual soundproofing procedure. This aeroplane is an 18-passenger bi-motor powered with supercharged 14-cylinder air-cooled geared engines developing each 815 h.p. Controllable pitch propellers (230 m./sec. tip speed at 66 per cent.). Full monocoque construction; single cabin. Floating front bulkheads. Floating floor. Shear type engine suspension.

We flew the aeroplane at its rated altitude and normal cruising speed 66 per cent. of power, speed 305 km./h. (190 m.p.h.) and before making any actual acoustical measurements we explored all accessible parts and panels of the structure with a hand vibrometer, an instrument consisting of a very heavy handle and an indicator gauge equipped with a sharp pointer which gives a rough idea of the magnitude of mechanical vibration. We found that at stations 1 to 5 and 4 to 6, Fig. 13, the skin vibrated about 0.04in., stations 5 to 9 the vibration was practically nil (less than 0.02in.), from 9 to 13 we had about 0.025in., and toward the end from 13 to 17 we again had 0.03in. In the bar and right in front of station A and B the vibration was very marked and at the level of the window was 0.05in.—from previous experiment on other aeroplanes decidedly too much. Certain panels displayed the known " oil canning " effect and were so marked. This effect is most marked on vertical bulkheads and partitions and on this aeroplane was most pronounced on the partition separating the wash-room and the baggage compartment from the cabin. The average noise level in the cabin as a result of 118 measurements was 94—rather more than expected. Upon landing all bad panels were reinforced with suitable channels of omega or " z " section. The bracing is done best by arranging those reinforcements to run diagonally.

A second test flight was made and the noise level dropped showing an average of 91 db. The expenditure of weight to accomplish this attenuation was 2 kg. (4.4lbs.), a convincing demonstration of what can be done with the structure before any acoustical material has been even thought of.

At the next test we began to measure noise levels at all stations and made a frequency analysis at stations 19, 23 and 27. The analysis at stations 23 and 27 showed what anyone would expect, predominance of the fundamental exhaust frequency, *i.e.*, $(14 \times 2{,}100)/(2 \times 60) = 163$ cycles and propeller $\{(3 \times 2{,}100)/60\} \times (\frac{7}{5}) = 70$ cycles. We could not explain, however, the sudden change in the 512-1,024 component between the reading taken at sections 19 and 23. Only a local source of sound could be the cause and our attention was concentrated to find it. It was soon found. A whole section below the floor vibrated with an amplitude of about $\frac{3}{16}$in., due undoubtedly to the fact that this panel was large, practically flat and right behind the propeller disc. When pressed with a rubber-soled shoe the vibration stopped, and while the total noise level change could hardly be noticed with the instrument, it was very apparent


Loudness, Intensity and Amplitude of Wall Vibration of a Given Aeroplane
Before, During and After Acoustical Treatment
1) No Treatment Whatsoever
2) After Removing Panel Drumming
3) First Layer Installed
4) Second Layer Installed
5) Trimming Installed
6) Loudness Test - Kingsbury Network Used
Propeller Disc
Vibration "Heavy" - Treatment 'R'
Vibration Light To Medium Light Treatment 'A'
Vibration Medium Treatment 'R'
Section A
Noise Max (6)
Section B
Noise Min (6)
Section C
Noise Average (6)

Stations		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	A	B	
First. Vibration Amplitude Test		0.04	0.04	0.03	0.03	0.03	0.04	0.02	0.04	0.04	0.01	0.05	0.025	0.025	0.05	0.05	0.03	0.04	0.03	Under Window											0.07	0.08					0.09	0.10	inches
Second. Vibration Amplitude Test		0.03	0.04	0.03	0.03	0.03	0.04	0.02	0.01	0.01	0.01	0.02	0.015	0.03	0.03	0.025	0.02	0.02	0.025	No Data Taken											0.05	0.06					0.04	0.05	
Intensity	Noise Test (1)	93	92	94	94	94	92	90	89	89	86	85	90	89	87	86	90	90	90	94	93	90	87	89	86	84	88	90	93	93	94	94	93	92	91	90	90	98	97	
	Noise Test (2)	92	91	92	93	92	90	90	88	87	86	89	89	88	86	86	88	89	89	91	90	90	87	88	84	84	85	90	90	90	91	92	93	93	91	89	89	92	94	
	Noise Test (3)	85	84	85	86	88	86	83	82	80	80	81	82	81	80	80	80	81	82	82	83	84	84	81	82	79	78	82	83	87	85	84	85	83	85	86	82	82	87	88
	Noise Test (4)	77	76	77	76	79	75	74	74	76	74	75	76	75	74	74	75	76	76	76	76	77	75	76	73	72	75	76	87	84	75	75	75	75	75	74	74	75	76	
	Final Test (5)	70	70	69	69	69	70	68	68	69	68	70	70	70	70	70	70	69	71	72	69	72	70	70	69	68	69	69	85	84	68	68	70	73	73	74	74	72	70	
Loudness Test (6)		68	65	64	64	65	66	66	66	65	64	65	66	66	66	66	66	65	69	67	67	68	68	67	67	65	65	65	80	80	68	66	69	70	72	72	72	69	69	

Decibels above 1 mb

Fig 13

to the ear, as our ears are so much more sensitive to high frequency sounds than to low ones. Owing to interference with other structural parts, a bracing was out of question, so a layer of sound deadening cement (a conglomerate of asphaltum, lead oxide, cork and rubber, called " cut back " by the automobile trade) was applied; further, a corrugated dural sheet was riveted to the panel and after this modification the frequency analysis became as expected. (Total weight 1.5 kg.)

We were then ready for the first step in acoustical treatment which must accomplish a dual purpose, namely, (*a*) damping any residual panel vibration so that the amplitude will be uniform and will not exceed 0.012in., and (*b*) absorb high frequencies as much as possible.

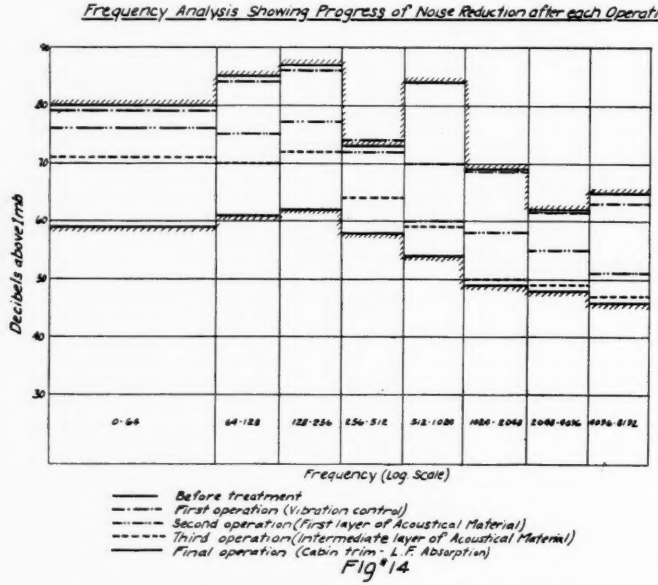
The section from stations 1 to 5, therefore, was treated with a material made of Kapok and paper pulp (Specification RX) about $\frac{1}{8}$in. thick. The material is coated on one side with a rubber emulsion and is used where vibrations are " heavy " or up to 0.05in. Sections 9 to 13, where vibrations were " light," was covered with a similar material (Specification A), but the material is lighter, less dense and more flexible. Sections 13 to 17, where vibration was " medium," was covered with a material similar in texture to Type RX and A, but slightly heavier (Specification R). The material is glued to the skin with a special glue made mostly of emulsified latex. The front and rear bulkheads were installed and our second acoustical test began. The average noise level dropped to 85 db., showing that the absorption in the aeroplane was properly chosen. In fact, recalling the formula noise reduction in $DB = 10 \log \Sigma A/\Sigma T$, ΣT remained constant, ΣA was increased about five times, hence decrease of noise $10 \log 5 = 10 \times 0.698 = 7$, proving the correctness of our formula and procedure.

The second test also showed that the noise was greater at the ends of the cabin and least in the centre, therefore we subdivided the cabin into three sections and arranged our intermediate layer of acoustical material in such a way as to get a uniform or nearly so noise level in all parts of the cabin. Section A was treated with Specification Q_3, section B with Q_2 and section C with Q_1—a Kapok material similar in chemical composition to type A material, but quilted between two layers of cotton batiste; Q_1 one, Q_2 two, and Q_3 three layers. The intermediate layer, bearing in mind the theoretical considerations, must float in an air space. It is very easy to accomplish such a construction on the ceiling by simply drilling small holes six to eight inches apart in the bulkheads and stringing some wires longitudinally and suspend the material. But on the sides a different way of fixing the quilted material must be thought of. Small pieces of cork or balsa wood are nailed to the first layer, the second being attached by means of small tacks is a practical and simple solution.

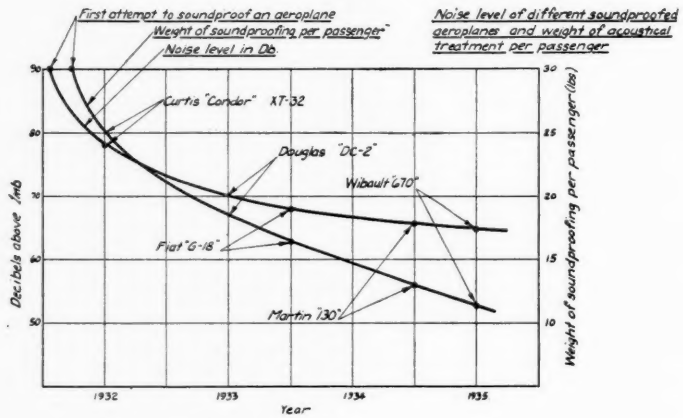
We were very fortunate to have another test flight after the intermediate layer was installed. The data are shown on Figs. 13 and 14 and the frequency analysis on Table II. We see that the high frequency component has become very small and that the noise level has further decreased and also become practically uniform. The remainder of treatment must be concentrated to eliminate the 60 and 128 to 256 cycle components and naturally we will use the scheme of a stretched diaphragm as it is the only one known which will be efficient. The simplest way to get a stretched diaphragm is to use linen or cotton aeroplane fabric and dope it. Experience has taught us how to control the stretch during installation, so we can control also the peak of absorption. The cabin was again divided into three sections and thus we had three areas which in proportion to the magnitude of the low frequency component would absorb the same most efficiently. The section " A " had an absorption of 55 per cent. at 64 cycles; " B " 70 per cent. at 256 cycles; and " C " 50 per cent. at 128 cycles. The installation and control of stretch of the fabric is not easy because the damping felt has to be held out of contact with the fabric while the dope is applied, and only after the dope has dried the felt can be glued. One method which is employed consists in suspending the felt on temporary wires, finishing the doping and then taking out the wires

and letting the felt fall upon the fabric. On side walls another scheme must be employed.

The last test was made and the noise level dropped to 69 (intensity scale) and to 65 (loudness scale) giving an aeroplane in which at 200 m.p.h. conversation can be carried on in an ordinary tone of voice and which can be classified as a very comfortable vehicle. Fig. 14 and Table III show a very even distribution



Fig°14



Fig°15

of noise, the frequency analysis shows a slight unbalance, only at 64-128 cycles, and the test with ventilators full open or full closed demonstrates that even ventilating noises can be greatly eliminated, as the difference of 0.5 db. can hardly be regarded a difference (instrument and observer error).

What is the weight expenditure of such an efficient aeroplane soundproofing? An interesting chart, Fig. 15, giving progressive diminution of weight and increased quiet is reproduced and it can be safely said that the weight per passenger is not excessive. Looking at the weight situation from another angle it can be stated that it will amount to about 2 per cent. of the gross weight for aeroplanes up to 7,000 to 8,000lbs. and 1.5 per cent. of the gross weight for crafts up to 25,000lbs., and about 1 per cent. in very large crafts. On the Martin " 130 " (51,000lbs.) the total expenditure was 560lbs. or 1.1 per cent.

Space does not permit me to go further into the problem of comfort—heating, proper chairs, freedom from oscillation, etc., all those elements capable of producing abnormal stimuli and causing discomfort. They have been taken care of by other specialists and the results of this intensive study has been more than gratifying. About one million satisfied passengers flew in the U.S.A. in 1935 and the number of passenger miles reaches astronomical figures.

TABLE III.

FREQUENCY ANALYSIS SHOWING PROGRESS OF NOISE REDUCTION IN AN ACTUAL BI-MOTOR 18-PASSENGER AEROPLANE.

Filter.	Station 19* No Soundproofing. Decibels.	Log *EQT*.	Station 23* No Soundproofing Decibels.	Log *EQT*.	Station 19* First Layer Inst'd. Decibels.	Log *EQT*.	Station 19* Second Layer Inst'd. Decibels.	Log *EQT*.	Stations 23* and 19* Final Layer. Decibels.	Log *EQT*
0-64	80	100	79	79	76	40	71	12.5	59	0.97
64-128	85	316	84	252	75	31	69	7.9	61	1.25
128-256	87	501	86	398	77	50	72	15.9	62	1.59
256-512	73	20	74	25	70	10	65	3.1	58	0.63
512-1024	84	252	70	10	60	1	59	0.8	55	0.31
1024-2048	69	8	69	8	58	0.6	50	0.1	49	0.08
2048-4096	63	2	63	2	56	0.4	49	0.08	48	0.08
4096-8192	65	3	63	2	51	0.1	47	0.05	46	0.04
Total	93	1202	89	778	81	133	76	40.3	69*	4.95

The decibel figures in this table are taken as above 1 millibar—*not* corrected for the ear response curve.

* If this figure is corrected for the ear response curve (Kingsbury network at 60 db.) it will become 65 db.

While we are proud of our contribution to comfort in air travel we have not forgotten nor do we hesitate to put it on record that our work would have been seriously handicapped if it were not for Dr. Davis' paper " Noise." This publication is still the " Bible " for anyone who wants to soundproof aeroplanes.

DISCUSSION.

Mr. D. R. PYE (Deputy Director of Scientific Research, Air Ministry, *Fellow*): The Society must count itself fortunate in having the opportunity of hearing Dr. Zand speak on the subject of noise suppression, of which he had made a concentrated study in recent years. It was pleasant, too, to welcome a lecturer from the U.S.A., and the spontaneous form of Dr. Zand's lecture had added to the pleasure of listening to it. He (Mr. Pye) was glad to hear the tribute which Dr. Zand had paid at the end of the lecture to the work of Dr. Davis. It was gratifying to know that the work which had been done at the National Physical Laboratory was regarded so highly by Dr. Zand and the engineers in America, who had been doing this soundproofing with so much success. If they had not in this country progressed so far in the practical application of silencing, it was at any rate satisfactory that much of the essential data for doing so was due to research work here.

He had had the pleasure in the spring of this year of doing a fair amount of flying on the American air lines, and he must say that they were extremely

comfortable, even for journeys of very considerable duration. There was still, it seemed to him, a good deal to be done with regard to low frequency vibration. Dr. Zand had spoken of an interesting method of dealing with that by means of the damped resonator. Possibly the introduction of this method might be subsequent to the completion of the air liners of which he (the speaker) had experience. Certainly in the Douglas machines in which he had travelled, he had been more conscious of an unpleasant drumming than of any noise more highly pitched.

The lecture had been entirely devoted to the soundproofing of aeroplanes and the reduction of noise from the point of view of the passengers. That, of course, was the aspect of the work on which Dr. Zand had concentrated, but he thought perhaps it was not inappropriate to say that he felt that the reduction of noise was of primary importance, not only from the point of view of the passenger, but also from that of persons on the ground. Personally, he lived in London, and he thought that Londoners were better off than people in many country districts from the point of view of what they suffered from aeroplanes over their heads. There was a growing volume of protest from many districts where air services were being developed, and those who were interested in aviation were in serious danger of incurring widespread unpopularity owing to the noise which their machines made. At the Royal Aircraft Establishment and elsewhere, some considerable progress had been made in the way of improved silencers for the engine exhaust, and it was now possible to design silencers which gave a substantial reduction of noise for a very small loss of engine power, although still with a loss of performance through extra weight and head resistance which placed limitations on their acceptability. He hoped that Dr. Zand would follow up his work for the comfort of passengers, by turning his attention to minimising the discomfort of people on the ground.

Although he had not any questions which he wished to put to Dr. Zand himself, no doubt there were aeroplane constructors present who would wish to question him about the application of his methods, and they were the persons best qualified to do so.

Mr. C. C. Walker (Chief Designer, Messrs. De Havilland, *Fellow*): The diagram which Dr. Zand had shown with the three different propellers was very interesting, and it would be useful to know what power was going through those propellers. Perhaps Dr. Zand did not consider that that had much bearing on the subject. In connection with the noise made by propellers it was very easy to ask questions, and one did not necessarily do so to get them answered, but the nature of the noise was rather important. One would like to know whether the tip speed in any given propeller, say the two-blade one, was a dominating thing. Would the tip of such a propeller make the same kind of noise if it was travelling straight through the air or had the effect of rotation something to do with it? If rotation was concerned, would the substitution of four blades for two affect that particular part of the phenomenon?

He wished to associate himself with what Mr. Pye had said about the importance of noise of aeroplanes from the point of view of people on the ground. In that connection he had noticed that a very high tip speed propeller seemed to make excessive local noise with respect to the plane of rotation to a much greater extent than was shown, apparently, on Dr. Zand's diagram. The time had now gone by when it was necessary to have loud exhaust noises, except under rare or possibly war conditions.

Professor G. T. R. Hill (Professor of Engineering, University College, *Fellow*): When he came to that meeting he knew very little indeed about the question of soundproofing, but the able way in which Dr. Zand had put forward his views had been very informative, and it was delightful to see how he had the whole subject at his finger tips. He felt that the fact that Dr. Zand did not read the paper but spoke extempore was a very great advantage to his audience.

The consideration of the question of noise by engineers seemed to him to mark

an advance in civilisation as a whole. In the old days the engineer used to produce something and if the sound was bad that had to be put up with, just the same as if the mechanism had a bad appearance or a bad smell. Those things were in the olden times simply not regarded. The engineer nowadays had to make his constructions look nice, sound nice, and even smell nice. The makers of one of the most popular cars on the road had employed a real artist to deal with the bodywork in order that they might satisfy the æsthetic sense. In the lecture that evening they had had an instance of the sound artist coming into the engineer's job.

He wondered if Dr. Zand had dealt at all with the question of smell. He believed that many people were seasick, not because of the motion of the vessel, but because of the smell in the confined space—the smell of grease, for example, coming up from the engine-room. He had never heard of any machine or instrument for measuring smell, but it seemed to him that smell was one of the things that the modern engineer must deal with. Ventilation and smell were closely allied, and it would be interesting to know what Dr. Zand had to say about that.

Mr. JOHN L. HODGSON (*Associate Fellow*): He wished to congratulate Dr. Zand on his lecture and to refer to the question of the suspension of the engines by rubber in tension. He would be glad if Dr. Zand would elucidate the matter further by a sketch on the blackboard. It seemed to him that engine suspension by rubber in compression might be more reliable than suspension by rubber in tension.

In the method of absorbing the low frequency vibration by means of stretched diaphragms backed by felt, how was the tension of the diaphragms maintained?

The question of external noise seemed to be important, and it would be interesting to hear why Dr. Zand had abandoned the use of mufflers. One had to use some kind of exhaust silencer in the case of motor cars. Was not something of this kind necessary to silence the noise outside the aeroplane?

Again, had Dr. Zand done anything with regard to the view of the passenger from the aeroplane? For his own part he always preferred to travel at the back of a small aeroplane so that things outside could be seen. In large aeroplanes the view of the passenger was apt to be interfered with by parts of the structure itself.

Captain J. L. PRITCHARD (Secretary of the Society, *Hon. Fellow*): During the last few months he had been looking into the question of the speeds of aircraft from the point of view of obtaining very high speeds indeed. Dr. Zand had said the faster the vehicle the greater the noise it made. Frankly, he found this difficult to believe. What was going to happen when the speed in flight was equal to the speed of sound—an achievement which was presumably going to be brought about at 40, or 50,000 feet in a few years time?

As they approached the speed of sound, it seemed to him, on Dr. Zand's theory, that they would get such a frightful noise that nobody would be able to live.

Again, how was the noise affected by height? A machine might be noisy at 5,000 feet; did it become much quieter at 50,000 feet? It should be remembered that the pressure in the cabin would still be of the order of that at ground level, and not, of course, the normal pressure at 50,000 feet.

Dr. W. F. HILTON (N.P.L.): There was one point which resulted rather differently in Dr. Zand's findings from work he had done at the R.A.E. under Professor Bairstow (Imperial College). Dr. Zand had shown a curve of airscrew noise against tip speed. It was his experience that, within limits of experimental error, this curve was a linear one right up to high tip speeds (1,300ft./sec.), although the sound changed considerably in its character.

With regard to Captain Pritchard's statement, he thought it was fairly evident that in a machine going at or above the speed of sound, a passenger would hear no sound at all.

Major KENNEDY (Hon. Treasurer of the Society, *Fellow*): Practically the whole of the lecture had been devoted to the consideration of transmission of sound

and very little appeared to have been done with regard to the origin of the sound. In that connection he thought it ought to be put on record that in the early days of motor transport very noisy conditions prevailed, and the inhabitants of Weybridge, near Brooklands Track, made such protests that ultimately the restrictions at Brooklands were made even more rigorous than anywhere else. Brooklands was now the only place where one might not take a noisy motor vehicle.

Dr. Zand had dealt only with the question of ventilation from the point of view of letting in so much air. He had not dealt with the question, which he felt would ultimately become very important, of air conditioning in the cabin. He understood that there were very large buildings in America in which the windows were never opened and yet the heating and ventilation were so managed that the air was perfectly conditioned. He took it that this question of air conditioning would become of real importance.

Mr. DENMAN (*Associate Fellow*): He associated himself with the tribute paid to Dr. Zand's skill in soundproofing the Douglas, particularly. He had had the pleasure of riding twice in that machine and the quite remarkable uniformity of the noise produced was something which had impressed him very much. There was no predominating or particularly irritating noise. That led him to ask Dr. Zand whether he had made any experimental research into the frequency distribution of the type of noise which was most easily tolerated. He believed, with Dr. Pye, that the noise component which was unpleasant was a very low frequency disturbance. In connection with the question of mufflers and exhaust boxes, he instanced some experiments at Kenton on a small German monoplane. This machine was always very quiet, but the introduction of a muffler, of American origin he believed, produced a very noteworthy further reduction.

Mr. OWNER (*Associate Fellow*): The lecture contained several points of extreme interest to engine designers. One of these was the question, already raised by several speakers, as to the advisability of using a silencer. He thought that American practice had differed from English in respect to the tip speeds of airscrews, which had been commonly higher than those used in this country. He believed that an exhaust silencer would become a practical necessity. Another point was rubber mounting. This was not directly concerned with the subject matter of the lecture, but it would be interesting to know whether any improvement in elimination of engine vibration had occurred as a result of the adoption of that mounting, and whether there had been cases incidentally where, although the rubber insulation was good for the purpose of soundproofing, it was undesirable from the point of view of engine vibration and its transmission.

Mr. F. S. BARTON (R.A.E.): Could Dr. Zand inform the meeting whether he used the subjective or objective methods of noise measurement, and if the latter, what type of equipment he favoured? Had he also considered the problem of soundproofing modern military aircraft with enclosed cockpits from the point of view of greater comfort and efficiency of the crew?

Mr. NAZIR (*Associate Fellow*): He asked in connection with tip speeds, if the tip form had any relation to soundproofing of the aeroplane at all; and if so, whether sharply tapered tips were any worse in this respect than others.

Mr. GORDON ENGLAND (*Fellow*): Dr. Zand had not touched on mechanical noises due to the engine. Did he consider that his flexible mount eliminated them substantially? It would be interesting to know whether he had made any experiments on the relative noises of a flexibly mounted power unit and one in which the power was rigidly fixed to the aeroplane. Was there, under certain conditions, vibration set up on the tip of the propeller? It seemed to him that this must, to a certain extent, be so, and probably would increase the noise. Further, had Dr. Zand data on the results of soundproofing and ventilation as affecting the sick list of passengers? Could Dr. Zand say what effect the colour scheme in the internal observations of the aircraft had upon the comfort of the passengers

and their proneness to sickness? He believed that it was now most uncommon for anyone in America to be airsick.

Mr. H. BELART (*Associate Fellow*): He wished to ask one question concerning the soundproofing of material. It seemed to him that the worst source of noise, namely, the airscrew had not been helped very much. As the airscrew was rather a small object. and the maximum intensity was in the plane of rotation, it seemed that one might apply some special measures near this plane to insulate the fuselage from the airscrew noise. It had been indicated in this lecture that the best soundproofing material was something which had high density but no rigidity, *i.e.*, something being absolutely flexible. He remembered seeing a report on the effect of a falling water screen on a cooling tower, which had a very remarkable effect in reducing the noise of a fan located inside. Was it possible to use such a screen of water on a small area of the aeroplane to insulate against airscrew noise?

REPLY TO DISCUSSION.

Mr. D. R. PYE.—It would be indeed fortunate to know means of silencing aircraft so that the people on the ground could not hear the aeroplane. As long, however, as present means of propulsion are adhered to it is quite unlikely that the problem will be solved. As to the very unpleasant low frequency sound Mr. Pye heard in the Douglas it must be emphasised that propeller beats—due to poor synchronisation of engines on the part of the pilot are such low frequency sounds, they are much more apparent in a quiet aeroplane than in a noisy one. He has repeatedly been admonishing pilots to synchronise engines, but some airmen are not conscious of the importance of synchronisation. Since, however, in the U.S.A. automatically controlled adjustable pitch propellers are more and more used the phenomenon of beats will rapidly disappear.

Mr. WALKER.—750 h.p. was being absorbed by the propeller in question. The airscrew noise analysis is quite difficult to accomplish and requires great care in the matter of separating the components. This work has been admirably pursued by Juichi and Obata, of the Tokio Imperial University, Vol. VI, 13 and 14, July, 1932. The N.A.C.A. in their Report 526 gives also some information on the subject. We have in effect two principal groups of frequency components:—

"(*a*) The low frequency component or the 'sound of rotation,' which is no doubt due to the pressure difference of the two sides of the blades. Naturally, the frequency of this sound will be (nX r.p.m.)/60, where n is the number of blades. Confirming the results of the Japanese investigators, we found that very often a sub-audible vibration equal to the r.p.m. of the propeller accompanies this sound, which is due in all probability to the very slight unbalance of the blades.

"(*b*) The whine or tearing sound, which is the high frequency component of the propeller sound, is attributed by the Japanese investigator to the 'vortices shed from the blades.' The wave form of this component is very complicated, as would be expected, due to the fact that the propeller section varies in form and has a speed from zero at the hub to the tip speed at the tip.

"The fact that the blade flexes both in azimuth and fore and aft adds a further complication. There seems to be no way at the present writing to predict what the predominant frequency of this sound will be. The magnitude of the high frequency component is, in comparison with the low frequency, about 30 to 60 per cent. smaller."[18]

It is also believed that rotation gives a special component to the spectrum—no detailed data are available. If a four-bladed propeller is substituted for a two-bladed one then, according to Davis, the noise generated will be roughly 10 db. less. Naturally the predominant or fundamental frequency will be doubled. The fact that instruments might register a linear dependence between tip speed and noise is very possible. It should not be forgotten that the wave form and not

[18] "Acoustics and the Aeroplane," by S. J. Zand, S.A.E. Journal (Transactions), Vol. 34, No. 2, page 44.

alone the amplitude governs loudness. The curve represented in the lecture was obtained by the use of the subjective (loudness) method. At speeds near the velocity of sound an entirely different wave form (compression wave) is generated, which may account for the loudness increasing much faster than the intensity.

Mr. HILL.—Mr. Hill's question is very important. The answer can be found in Mr. Bassett's paper *loc. cit.*, " In some of the early attempts at cabin heating, air was heated by the exhaust manifold and then taken into the cabin. Such air frequently smelled scorched or occasionally smelled of oil." This condition was found unbearable. *Even a trace of smell causes extreme discomfort in the air.* Smell can be measured and the unit is a " mio " used by perfume and deodorant manufacturers. Smell similar to taste can be measured, so far, only objectively. The elimination of smell had probably a great effect on air sickness, but since " comfort conditioning " takes into consideration all factors and has been introduced simultaneously no figures are available as to the individual contribution of each comfort component. The fact that the number of airsick passengers over Transcontinental and Western Air Lines (conditioned Douglas's) has decreased to a vanishing point is significant. The percentage of airsick passengers in 1929-30 (Ford Tri-motors) on this line was about 50 per cent., and now in 1935 (Douglas's) is about 1 per cent.

Mr. HODGSON.—Mr. J. L. Hodgson's question regarding engine suspensions seemed so important that the writer enlarged upon the subject when he had a chance to prepare the paper for publication, and believes that the data given are sufficiently clear and complete to permit anyone to lay out a satisfactory shear type mount.

The tension of the diaphragm can be maintained constant. Unfortunately the author is not free to disclose the scheme yet, as the application for patents on this construction are still pending.

There seems to be a general misunderstanding regarding the writer's attitude to mufflers. They should not be discarded, but as long as the propeller makes a greater noise than the engine exhaust a muffler is an unwarranted luxury, both for the people on the ground and the passengers in the cabin. All that is necessary is to bring the exhaust noises below the propeller noise. In general a collector and tailpipe will accomplish this feat, saving at least 50lbs. per engine and diminishing the drag by a few per cent. If a propeller is invented which will make a noise of, say 50 db., then a muffler attenuating the exhaust to 50 db. or thereabouts will be very much in need.

Had Mr. Hodgson travelled in a modern aeroplane especially through the American Middle West at 10,000ft. for six hours or so? If he had he would agree with the writer that windows are practically unused on such trips. The passengers see very little and what they see is so monotonous that after thirty or so minutes either go to sleep or converse with each other, read, play bridge. In a well ventilated, quiet aeroplane there is enough distraction besides looking at wheat fields. It may be different on the continent. Windows for good acoustical treatment should be small (14in. by 18in.). They are highly reflective and contribute nothing to the absorption.

Captain PRITCHARD.—If an aeroplane could fly in vacuo there would be no noise generated. In a previous paper by the author (S.A.E., Feb., 1934) a curve is reproduced showing noise of a given aeroplane plotted against altitude. Engine speed constant. At sea level the aeroplane registered 73 db., at 20,000ft. 60 db. If aeroplanes ever reach the speed of sound the writer will be forced to join the engineers employed on relief jobs and dig ditches—as the cabin would be perfectly noiseless.

Dr. HILTON.—An attempt has been made in answering Mr. Walker's question to include in the explanation for Dr. Hilton's query. It should not be forgotten that the data was taken in 1932 when the measuring equipment and methods were not as precise as they are now. Thus the conclusions may be in error.

Major KENNEDY.—Major Kennedy's remark is very timely. As a matter of fact certain airlines condition their cabins on the ground. In Kansas City, for example, the midday temperature in summer at the air field can be 110-120°F. with a humidity at about 90 to 95 per cent. A small truck containing a refrigerator and dehumidifier is wheeled in front of the aeroplane, and through a hose this air conditioner pumps cool dry air into the cabin. Passengers boarding such an air liner find it delightfully cool and after take-off the cabin stays cool because our American aeroplanes fly at 8,000 to 10,000 feet. Air conditioning in large transport aeroplanes is a coming thing, with some firms already adapting their equipment for such an installation.

Mr. DENMAN.—The irritating noise which Mr. Denman might have heard on the Douglas was undoubtedly a piece of metal trim loose or a seat belt rattling. This type of noise unbalances the acoustical spectrum. Nature loves balance in all things giving us warning by the sensation of discomfort if things are out of balance. In working out an acoustical treatment the best method to follow is to attenuate all the components of noise in proportion to their " annoyance " effect. If the residual noise curve follows approximately the ear response curve the spectrum is balanced. In such a sound field a sudden increase of the high frequency component, such as produced by a loose fitting, etc., will be very distracting. Occasionally, owing to poor maintenance, this phenomenon occurs on the Douglas. In order to prevent such happenings on the author's latest designs great care has been exercised to design non-rattling cabin trim. The complete elimination of all parasitic sounds has been achieved on the 66 db. Breguet Wibault (1936). Referring to the muffler question of the small German plane, it can be said that probably this aeroplane had a quiet propeller and a noisy engine. The muffler made some improvements, but they were probably of the magnitude of 2 to 3 db. only.

Mr. OWNER.—The question of silencers is believed answered as mentioned, referring to previous discussions. It has never been found that flexible engine suspension was undesirable from the engine makers' point of view. The smoother the engine, however, the better for the engine, the structure and the passengers.

Mr. BARTON.—Both methods are used by the lecturer. Each method has its individual advantage so that it is hard to state generally which is preferable. For quick work the subjective is unexcelled as the tick of a watch, to which the observer is callibrated, will give good results, so will a shilling tuning fork. For exact measurement the objective method is the only proper one. The military pilot, especially the navigator and the bomber in a large combat aeroplane is absolutely entitled to some comfort. It is possible to soundproof an enclosed cockpit, and give the crew a noise level of about 75 to 78 db. without sacrificing too much weight or space. The author has met, however, with such scepticism on the part of military authorities that he has only done such work once.

Mr. NAZIR.—No data in the writer's possession on the subject—see " Research on Model Airscrews," by G. P. Douglas (*Aircraft Engineering*, March, 1936).

Mr. G. ENGLAND.—The test in regard to Mr. Gordon England's question has been made after the paper has been read—they are mentioned in the corrected paper. It is presumed that under certain conditions, sharp turns or sudden changes of the angle of attack might increase the tip vibration and thus increase momentarily the noise. Under normal cruising conditions this phenomenon does not seem to occur.

Air sickness is practically non-existent on T.W.A.,[19] E.A.L.,[20] American Airlines, Pan American, K.L.M. and Swisair air lines, which use scientific comfort conditioning and which also use gyropilots. On other lines where such equipment has not yet been installed sickness is still a common occurrence. Colour schemes are quite important to the well being of passengers. Red, terra

[19] Transcontinental & Western Air Inc.
[20] Eastern Airlines Inc.

cotta, vivid green-silver, gold, and many gaudy colours should not be used. A two-tone grey, cream, palid blue, light green, dull or flat colours, without distracting contrast are probably the best. (A warning, keep away from modernistic interior decorator.)

Mr. BELART.—Mr. Belart's suggestions are quite interesting academically—but how about freezing, evaporating, corrosion, weight and other associated possible troubles? For the time being rock wool, sea pack, Kapok and felt will have to be used.

The author has been given way too much personal credit for the work he has been doing in trying to make aeroplanes more comfortable. But this research was a war on decibels and, as usual in cases of conflicts, the generals get the medals and the soldiers are soon forgotten, except in America where they get a bonus handed out to them twenty years later. He hopes that his associates and friends, too numerous to be mentioned by name, will get ultimately the recognition and honours they deserve. He wants to thank his many friends of the Royal Aeronautical Society for the privilege of having been with them this evening and hopes to return to these shores to do some actual work on British passenger aircraft.

The PRESIDENT: Once upon a time there was a Minister of Transport, who, like all Ministers of Transport, was in charge politically of the Electricity Commissioners. They had talked from 11 in the morning until half-past four in the afternoon about some new scheme for reorganising electricity in this country, and in the late afternoon the Minister turned to the Electricity Commissioners and said, "Do you know, it would clear my mind a lot if somebody would explain to me what a volt is." He himself was not quite in that position to-day, but he would like to know, in an ordinary man's way of speaking, what sort of noise 60 decibels represented. Could he buy a rattle, and by playing with it, produce a given number of decibels? There were some noises which one did not mind, and others which were quite intolerable. He believed that the lecturer would be perfectly happy with 20 decibels of, say, a cornet, but 20 decibels of a scratching slate would be intolerable.

He was pleased that Mr. Pye had brought them very smartly down to earth from the point of view of the "earth worm" listening to the aeroplane up above. It surprised him that no more work had been done on that side, because a silent aeroplane in the air had a military value. Here they had had a lecturer talking about comfort on the civil side. Professor Hill had tried to pat engineers on the back because they were now endeavouring to make things of beauty and to introduce comfort into their constructions. He could not help reminding him that they were all doing it only for filthy lucre, but of course it was an excellent thing when all the engineers concentrated on seeing that the feet of a passenger in an aeroplane were warm while his nose remained cold.

Joking apart, he could not help feeling that the sort of work that Dr. Zand was doing was going to have a very big effect on aviation, because a method of transportation would only prove popular and generally successful if people liked it, and for what Dr. Zand had done in the way of getting people to like air travel they owed him much appreciation. He proposed a hearty vote of thanks.

A vote of thanks was accorded and the meeting terminated.

CRITICAL SPEEDS OF A WIND TUNNEL FAN SHAFT.

By J. Morris.

In the design of a fan drive regard should be had to possible critical or resonant speeds which may result in failure of the system. It is not sufficient to arrange for the ordinary whirling speed to be well above the maximum running speed. In whirling the forced vibration arises from static or dynamic unbalance of fan and/or its shaft and the frequency of the forced vibration is the frequency of revolution of the fan shaft. Other important forced vibrations may however be set up. Thus, if the fan has six blades then there will be an aerodynamic reaction between the fan and model of a frequency of six pulsations per revolution of the fan shaft. If these pulsations are sufficiently powerful then, in the event of resonant vibration in the running range arising from the synchronisation of a frequency of vibration of the system with the frequency of these pulsations, the amplitude of the vibration may become sufficiently large for the system to fail. Let us consider the possibility of such resonance in the system diagrammatically illustrated in Fig. 1.

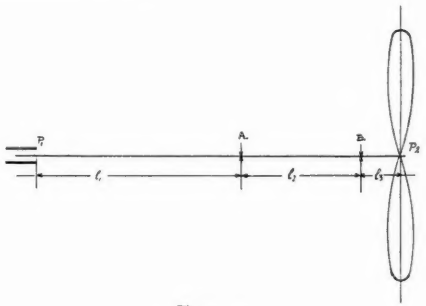


Fig. 1.

P_1ABP_2 is a straight shaft. At A and B there are short bearings. There is a long bearing at P_1 while at P_2 is attached a six-bladed fan.

To find the frequencies of lateral vibration of such a system when rotating with constant angular velocity we may proceed as follows:—

Consider the shaft on the two short supports A, B, and suppose there are loads P_1, P_2, respectively at the points P_1, P_2, designated for convenience points 1, 2, and otherwise free.

Let y_{11} = deflection at point 1 due to unit load at that point.
y_{12} = deflection at point 2 due to unit load at point 1 = also y_{21}.
z_{11} = deflection at point 1 due to unit couple at that point.
z_{12} = deflection at point 2 due to unit couple at point 1.
z_{21} = deflection at point 1 due to unit couple at point 2.

(N.B.—$z_{21} \mp z_{12}$.)

ϕ_{11} = slope at point 1 due to unit couple at that point.
ϕ_{12} = slope at point 2 due to unit couple at point 1 = also ϕ_{21}.

Let the masses of the loads be m_1, m_2; c_1, c_2, their polar moments of inertia; a_1, a_2, their lateral moments of inertia; then it may be shown* that the frequencies of lateral vibration of such a system will be given by $k/2\pi$, where k is given by the equation

$$m_1m_2\,(a_1-c_1\Omega/k)\,(a_2-c_2\Omega/k)\begin{vmatrix} y_{11}z_{11}y_{12}z_{21} \\ z_{11}\phi_{11}z_{12}\phi_{12} \\ y_{12}z_{12}y_{22}z_{22} \\ z_{21}\phi_{12}z_{22}\phi_{22}\end{vmatrix} k^8 - \left\{ m_1m_2\,(a_1-c_1\Omega/k)\begin{vmatrix} y_{11}z_{11}y_{12} \\ z_{11}\phi_{11}z_{12} \\ y_{12}z_{12}y_{22}\end{vmatrix}\right.$$

$$+ m_1m_2\,(a_2-c_2\Omega/k)\begin{vmatrix} y_{11}y_{12}z_{21} \\ y_{12}y_{22}z_{12} \\ z_{21}z_{22}\phi_{22}\end{vmatrix} + m_1\,(a_1-c_1\Omega/k)\,(a_2-c_2\Omega/k)\begin{vmatrix} y_{11}z_{11}z_{21} \\ z_{11}\phi_{11}\phi_{12} \\ z_{21}\phi_{12}\phi_{22}\end{vmatrix}$$

$$\left. + m_2\,(a_1-c_1\Omega/k)\,(a_2-c_2\Omega/k)\begin{vmatrix} \phi_{11}z_{12}\phi_{12} \\ z_{12}y_{22}z_{22} \\ \phi_{12}z_{22}\phi_{22}\end{vmatrix}\right\} k^6 + \left\{ m_1m_2\begin{vmatrix} y_{11}y_{12} \\ y_{12}y_{22}\end{vmatrix}\right.$$

$$+ m_1\,(a_1-c_1\Omega/k)\begin{vmatrix} y_{11}z_{11} \\ z_{11}\phi_{11}\end{vmatrix} + m_1\,(a_2-c_2\Omega/k)\begin{vmatrix} y_{11}z_{21} \\ z_{21}\phi_{22}\end{vmatrix} + m_2\,(a_1-c_1\Omega/k)\begin{vmatrix} \phi_{11}z_{12} \\ z_{12}y_{22}\end{vmatrix}$$

$$\left. + m_2\,(a_2-c_2\Omega/k)\begin{vmatrix} y_{22}z_{22} \\ z_{22}\phi_{22}\end{vmatrix}\right\} k^4 - \{\, m_1y_{11} + m_2y_{22} + (a_1-c_1\Omega/k)\,\phi_{11} + (a_2-c_2\Omega/k)\,\phi_{22}\,\}\, k^2$$

$$+ 1 = 0$$ where Ω is the angular velocity of imposed rotation supposed constant.

If now we make m_1, a_1 and c_1 very large then the load P_1 is virtually replaced by a long bearing. In these circumstances we put the coefficient of $m_1\,(a_1-c_1\Omega/k)\,k^4$ in the above equation in k equal to zero and thus obtain

$$m_2\,(a_2-c_2\Omega/k)\begin{vmatrix} y_{11}z_{11}y_{11}z_{21} \\ z_{11}\phi_{11}z_{12}\phi_{12} \\ y_{12}z_{12}y_{22}z_{22} \\ z_{21}\phi_{12}z_{22}\phi_{22}\end{vmatrix} k^4 - \left\{ m_2\begin{vmatrix} y_{11}z_{11}y_{12} \\ z_{11}\phi_{11}z_{12} \\ y_{12}z_{12}y_{22}\end{vmatrix} + (a_2-c_2\Omega/k)\begin{vmatrix} y_{11}z_{11}z_{21} \\ z_{11}\phi_{11}\phi_{12} \\ z_{21}\phi_{12}\phi_{22}\end{vmatrix}\right\} k^2$$

$$+ \begin{vmatrix} y_{11}z_{11} \\ z_{11}\phi_{11}\end{vmatrix} = 0.$$

To take a numerical example. Let the shaft P_1ABP_2 be solid and of $2\frac{1}{2}$in. o.d. Let the mass of the fan be 134lb. and let its polar moment of inertia be 128lb. ft.^{2}, the lateral moment of member being taken as half this. Let $l_1 = 9$oin., $l_2 = 5$oin. and $l_3 = 10$in.

Then using in. lb. wt. sec. units we have

$$m_2 = 0.35$$
$$a_2 = 24$$
$$c_2 = 48$$
$$y_{11} = (378 \times 10^3)/e \quad (e = EI)$$
$$y_{12} = (7{\cdot}5 \times 10^3)/e$$
$$y_{22} = (2 \times 10^3)/e$$
$$z_{11} = (-5{\cdot}55 \times 10^3)/e$$
$$z_{12} = (-0{\cdot}0833 \times 10^3)/e$$
$$z_{21} = (0{\cdot}75 \times 10^3)/e$$
$$z_{22} = (0{\cdot}217 \times 10^3)/e$$
$$\phi_{11} = (0{\cdot}107 \times 10^3)/e$$
$$\phi_{12} = (-0{\cdot}00833 \times 10^3)/e$$
$$\phi_{22} = (0{\cdot}0267 \times 10^3)/e$$
$$e = EI = (30 \times 10^6 \times \pi \times 1{\cdot}25^4)/4$$

* See "Strength of Shafts in Vibration" by J. Morris (Crosby Lockwood), § 147.

$$\begin{vmatrix} y_{11}z_{11}y_{12}z_{21} \\ z_{11}\phi_{11}z_{12}\phi_{12} \\ y_{12}z_{12}y_{22}z_{22} \\ z_{21}\phi_{12}z_{22}\phi_{22} \end{vmatrix} = \begin{vmatrix} 378 & -5{\cdot}55 & 7{\cdot}5 & 0{\cdot}75 \\ -5{\cdot}55 & 0{\cdot}107 & -0{\cdot}08\dot{3} & -0{\cdot}00\dot{8}3 \\ 7{\cdot}5 & -0{\cdot}08\dot{3} & 2 & 0{\cdot}217 \\ 0{\cdot}75 & -0{\cdot}00\dot{8}3 & 0{\cdot}217 & 0{\cdot}267 \end{vmatrix} \times 10^{12}/e^4$$

$$= 0{\cdot}0551 \times 10^{12}/e^4$$

$$\begin{vmatrix} y_{11}z_{11}y_{12} \\ z_{11}\phi_{11}z_{12} \\ y_{12}z_{12}y_{22} \end{vmatrix} = \begin{vmatrix} 378 & -5{\cdot}55 & 7{\cdot}5 \\ -5{\cdot}55 & 0{\cdot}107 & -0{\cdot}08\dot{3} \\ 7{\cdot}5 & -0{\cdot}08\dot{3} & 2 \end{vmatrix} \times 10^9/e^3 = 17{\cdot}58 \times 10^9/e^3$$

$$\begin{vmatrix} y_{11}z_{11}z_{21} \\ z_{11}\phi_{11}\phi_{12} \\ z_{21}\phi_{12}\phi_{22} \end{vmatrix} = \begin{vmatrix} 378 & -5{\cdot}55 & 0{\cdot}75 \\ -5{\cdot}55 & 0{\cdot}107 & -0{\cdot}00\dot{8}3 \\ 0{\cdot}75 & -0{\cdot}00\dot{8}3 & 0{\cdot}267 \end{vmatrix} \times 10^9/e^3 = 0{\cdot}24 \times 10^9/e^3$$

$$\begin{vmatrix} y_{11}z_{11} \\ z_{11}\phi_{11} \end{vmatrix} = (378 \times 0{\cdot}107 - 5{\cdot}55^2)\ (10^6/e^2) = 9{\cdot}64 \times (10^6/e^2)$$

The appropriate equation is therefore

$$0{\cdot}35\ (24 - 48\ \Omega/k) \times 0{\cdot}551 \times (10^{12}k^4/e^4)$$
$$- 0{\cdot}35 \times 17{\cdot}58 + (24 - 48\ \Omega/k) \times 0{\cdot}24\ (10^9k^2/e^3) + 9{\cdot}64 \times 10^6/e^2 = 0$$

or

$$0{\cdot}35 \times 0{\cdot}551 \times 24\ (1 - 2\ \Omega/k)\ (10^6k^4/e^2)$$
$$- 0{\cdot}35 \times 17{\cdot}58 + 24\ (1 - 2\ \Omega/k) \times 0{\cdot}24\ (10^3k^2/e) + 9{\cdot}64 = 0.$$

To find the whirling speed of the system we put $k = +\Omega$ in the above and thus obtain the equation in Ω^2

$$0{\cdot}462\ (10^3\Omega^2/EI)^2 + 0{\cdot}39\ (10^3\Omega^2/EI) - 9{\cdot}64 = 0.$$

The positive root of this equation in $10^3\Omega^2/EI$ is found to be 4.521, from which we find that

$$\Omega/2\pi = 81{\cdot}11 \text{ r.p.s.}$$
$$\text{or } 4{,}870 \text{ r.p.m. app.}$$

and this will be the whirling speed.

Suppose that the top speed of the fan is 1,800 r.p.m., there is no danger whatever from whirling in the ordinary sense.

Next we put $k = \mp 6\Omega$* in the equation in k. When $k = -6$ the equation becomes

$$0{\cdot}616\ (10^3 \times 36\ \Omega^2/EI)^2 - 12{\cdot}425\ (10^3 \times 36\ \Omega^2/EI) + 9{\cdot}64 = 0.$$

From the roots of the equation in Ω^2 we obtain two resonant speeds, viz. :—

(1) 345 r.p.m. (2) 1,710 r.p.m.

If now we put $k = +6\,\Omega$ the equation becomes

$$0{\cdot}308\ (10^3 \times 36\ \Omega^2/EI)^2 - 9{\cdot}993\ (10^3 \times 36\ \Omega^2/EI) + 9{\cdot}64 = 0$$

from the roots of which we obtain two further resonant speeds, viz. :—

(3) 380 r.p.m. (4) 2,140 r.p.m.

Thus the resonant speeds arising from the aerodynamic pulsations between fan blades and model will be

345, 380, 1,710, 2,140 r.p.m.

Another possibility of serious vibration may arise from the fact that in the particular fan each blade may have a separate resonance between its frequency when vibrating about its root regarded as fixed and an aerodynamic pulsation of frequency twice per revolution.

Thus, if a blade frequency in the thrust plane is 2,700 r.p.m. then when rotation is imposed the frequency will be given by f where

$$f = 2{,}700^2 + 1{\cdot}4\ N^2 \text{ app.}$$

where N = r.p.m. of the fan.

* See "Strength of Shafts in Vibration" by J. Morris (Crosby Lockwood), § 145.

If now we put $f = 2N$ we find that

$$N = 1{,}680 \text{ r.p.m. app.}$$

CONCLUSION.

It would appear in this case that resonant vibration due to the frequency of the aerodynamic pulsations from the blades of the fan synchronising with frequency of lateral vibration of the system arises at four speeds, of which three are in the running range and of these the highest will be the most serious.

There is also a resonant vibration between a blade frequency in fore and aft vibration with the forcing vibration of frequency twice per revolution which will act on each blade.

REVIEWS.

Elements of Diesel Engineering.

By Orville Adams. Published by Constable and Co., Ltd. Price 18/-.

This book is intended to be an introduction to the design, working, maintenance and repair of all types of Diesel engines, and it may be said at once that Mr. Orville Adams has produced a very useful book on these subjects. Being an American, he has naturally drawn on American experience, in fact certain well-known types of European engines are not referred to, but there is a mine of practical information to be found here, most of which is applicable to Diesels of all types.

The outstanding feature of the work is the stress which is laid on the importance of detail. Slight variations in the design of injection values, the curves of piston heads, position of valves, clearances in pump cylinders, all have a great importance in the satisfactory functioning of an engine, and in many cases the manufacturing of parts is extremely difficult owing to the great machining accuracy which is necessary. Mr. Orville Adams rightly devotes page after page to matters of this sort.

Obviously, where small pump parts, valves and apertures are concerned, the fuel oil cannot be too clean. In one instance of recent American practice the fuel oil is passed through a wool fabric filter and then through a bronze edge filter with a 0.0015 spacing, it is then delivered to the injection pumps. Further, there is a 0.003 jet type filter fitted above each suction valve, and another of 0.001 spacing in the injection nozzle. Such are the precautions considered necessary.

The book can be thoroughly recommended to all those interested in the subject.

Notions General sur la Reparation des Moteurs d'Aviation.

By Jacques-Roger Pierrot. Published by Imprimerie Union, 13 Rue Mercan, Paris.

As the French Air Service did not possess a suitable manual on the subject of the repair of aviation motors, a competition was arranged for the most suitable book. The competition was won by M. Pierrot with this work.

It is an exhaustive account of the various methods of reconditioning aero engines. It starts with a proposed layout of a suitable works, discusses methods of organisation and details of staffs required, and then goes on to discuss nearly every separate part of an aero engine, points out the places where wear is to be expected and then describes methods of repair. The book is copiously illustrated, largely with photographs of special tools used for certain repair operations, and it also deals thoroughly with methods of testing. It is, of course, a fact that differing engines differ from each other in the mechanical solution adopted for design problems, so the author has, in such instances, taken a typical solution, and has necessarily left the others to be dealt with by the operator with his remarks as a guide.

Possibly the part of the book which the reader will find most interesting is the description of extensive use of machinery for all sorts of repair work; the hand-operated tool is seldom referred to, and the file and the scraper are not often used. It would seem that several of the French aero engine makers make and supply special tools for reconditioning their own engines. Salmson and Gnome-

Rhone both make machines for grinding piston rings. In the past, repair work of this type was often the special province of the skilled fitter, and it appears that the machine tool is overtaking him in one of his last strongholds.

I regard this book as being of peculiar interest. All the methods described are practical, and there is on every page a large amount of information on all sorts of cognate matters, such as methods of measuring, etc., which would save an operator in this field a great amount of time. In fact it is an excellent treatise on the subject with which it deals.

MAINTENANCE OF HIGH SPEED DIESEL ENGINES.

By Arthur W. Judge. Published by Chapman and Hall, Ltd. Price 10/6.

In this book Mr. Judge has collected together a large amount of diverse information on Diesel engine maintenance and repair, most of which seems to have been collated from data supplied by the manufacturers, though some may have been obtained from published papers.

Such a compilation is possibly valuable as a rough guide to the type of maintenance required by these engines, but the information given would have been of real importance if the costs of the various processes had been given and analysed. Statements that certain maintenance precautions should be carried out at definite distance intervals are uninteresting unless supported by reference to ascertained costs. It is not apparent that the book would be of any real value to a user of any particular type of Diesel engine, who could easily get similar data direct from the manufacturer of his engines, but it may have some interest to those who are contemplating the use of such engines and who wish to understand something about their special problems.

The 604th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS.

A meeting of the Society was held in the Lecture Theatre of the Institution of Electrical Engineers at Savoy Place, Victoria Embankment, London, W.C.2, on Monday, February 17th, 1936, when a paper on "The Boundary Layer and Recent Developments," by Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S., was presented and discussed. In the chair: Lieut.-Colonel J. T. C. Moore-Brabazon, President of the Society.

The PRESIDENT: Professor Bairstow was a very old personal friend of his and a very old friend of the Royal Aeronautical Society, of which he had been a Fellow since 1914. Since that time, his friends were delighted to know, he had been elected, most deservedly, a Fellow of the Royal Society. He was fulfilling the duties of Zaharof Professor of Aeronautics at London University.

THE BOUNDARY LAYER AND RECENT DEVELOPMENTS

By Professor L. BAIRSTOW, C.B.E., F.R.S., F.R.Ae.S.

INTRODUCTION.

As time passes more and more knowledge of the flow of fluids past bodies accumulates and of this increase some becomes applied to the problems of the day. Boundary layer theory is being applied at the present time to the problem of the degree of polish which should be given to a wing in order to reduce its profile drag to a minimum. Tests in the compressed air tunnel at the National Physical Laboratory and in flight at Cambridge and Farnborough have recently been directed to this point and give quantitative assurance of the correctness of theory. In what follows, a survey is made of a group of theorems relating to the resistance of various bodies such as aerofoils and flat plates and more generally to streamline forms. The theorems are partly physical and partly mathematical and approximations are numerous and of very different degrees of validity. The equations of motion to be solved are known to an accuracy which satisfies all of us, but they are too difficult for solution by the mathematician; as a consequence some accuracy in physical conception is sacrificed in order to bring problems within the range that is soluble. Our subject divides itself into two sections, laminar and turbulent boundary theory, and in the first of these, departures from strict physical accuracy are moderate and such that theory seems logical. Turbulent boundary theory, on the other hand, strains the imagination to the limit and a great amount of empiricism remains even in the best efforts. Some new efforts to understand turbulence are being made—the R.Ae.S. has had a paper from Fage on one aspect of turbulence and G. I. Taylor has just presented a series of four papers on the subject to the Royal Society. With these aspects of turbulence the present paper is not concerned, space and time both setting a limit to the possibilities of a single lecture. What is attempted is a survey of our subject from the equations of motion to the calculation of profile drag and lift coefficient up to its maximum. In no case is a full analysis given and students wishing to go further will need to go to original papers for guidance. It is hoped that the present paper will be a good index to existing literature.

1. Equations of Fluid Motion.

The starting point for the solution of boundary layer problems is normally the equations of motion of a viscous incompressible fluid as given by Stokes and Navier and it is the extreme difficulty of direct mathematical solution that has led to the examination of approximate equations. These approximations range from relatively simple and logical changes following some physical conception such as the limitation of the effects of viscosity to a thin layer to assumptions which strain credibility almost to breaking point. An attempt will be made to indicate both the physical ideas of some of these approximations as well as the mathematical processes involved in translating physical ideas into formulæ. In no case is an example fully worked out, since any attempt to do so would run counter to an effort to give as concise a picture as I can of the state of the art.

The equations of motion in two dimensions for a viscous incompressible fluid are well known in the form

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-(1/\rho)\,\partial p/\partial x+\nu\Delta^2 u \quad . \quad . \quad . \quad (1.1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-(1/\rho)\,\partial p/\partial y+\nu\Delta^2 v \quad . \quad . \quad . \quad (1.2)$$

and the equation of continuity

$$\partial u/\partial x+\partial v/\partial y=0 \quad . \quad . \quad . \quad . \quad . \quad (1.3)$$

Equation (1.3) is satisfied by the assumption of a stream function

$$u=\partial\psi/\partial y,\quad v=-\partial\psi/\partial x \quad . \quad . \quad . \quad . \quad (1.4)^*$$

Eliminating p between equations (1.1) and (1.2) leads to the form

$$\frac{\partial\zeta}{\partial t}+u\frac{\partial\zeta}{\partial x}+v\frac{\partial\zeta}{\partial y}=\nu\Delta^2\zeta \quad . \quad . \quad . \quad . \quad (1.5)$$

where

$$\zeta\equiv\partial v/\partial x-\partial u/\partial y \quad . \quad . \quad . \quad . \quad . \quad (1.6)$$

A transformation of (1.5) introduces the idea of a Reynolds number. Express velocities as multiples of some standard velocity V which is independent of x and y and use a common length l as a basis for ratios of other lengths, *i.e.*, write

$$u_1\equiv u/V,\quad v_1\equiv v/V,\quad x_1\equiv x/l,\quad y_1\equiv y/l \quad . \quad . \quad . \quad (1.7)$$

then

$$\zeta_1\equiv\partial v_1/\partial x_1-\partial u_1/\partial y_1=(l/V)\,\zeta,\quad \partial/\partial t\equiv(V/l)\,\partial/\partial t_1 \quad . \quad . \quad (1.8)$$

and using (1.7) and (1.8) with (1.5) leads to the equation

$$\frac{\partial\zeta_1}{\partial t_1}+u_1\frac{\partial\zeta_1}{\partial x_1}+v_1\frac{\partial\zeta_1}{\partial y_1}=(1/R)\,\Delta_1^2\zeta_1 \quad . \quad . \quad . \quad . \quad (1.9)$$

where

$$R\equiv Vl/\nu \quad . \quad . \quad . \quad . \quad . \quad (1.10)$$

and by generalising the co-ordinates as indicated in (1.7) it is seen that solutions of the equations of motion involve only a single arbitrary coefficient R.

On this deduction most of the experimental work in aerodynamical laboratories is based and we have every confidence in the adequacy of equations such as those in equations (1.1) to (1.9) to account for observations of real motions whether steady or turbulent.

Vl/ν, *i.e.*, Reynolds number, is not a quantity which can be carried from one type of experiment to another without the use of arguments additional to those leading to (1.9), and in the literature of applied aerodynamics we have a whole series of Reynolds numbers, the significance of which corresponds with a series of definitions of V and l.

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* The sign given to ψ is arbitrary and there is a present tendency to use 1.4 instead of the convention adopted by Lamb. The reason is a desire to conform to Continental usage and its extensive literature.

For wing sections V is taken as the velocity of the wing relative to undisturbed fluid and l is the chord—mean chord in many cases. In boundary layer theory a different Reynolds number consists of a product using for V the velocity immediately outside a boundary layer and a length δ equal to the thickness of the boundary layer. In other cases, such as are associated with airship forms, a length is obtained by taking the square root of the wetted surface, and so on.

There is a Reynolds number for the tunnel in which a model is tested which is not necessarily the same as for the model. For this reason results in two tunnels are not strictly comparable, and though the difference is commonly spoken of as due to difference of turbulence in the two streams, it can equally be expressed as due to difference of Reynolds numbers.

The theoretical difficulties of our subject begin at attempts to solve equations (1.1) to (1.9), and something of physical accuracy is exchanged for mathematical necessities if any solutions at all of use in aerodynamics are to be obtained. As is usual in such cases, doubt must exist as to the applicability of the answers and frequent recourse is made to experimental checks.

One group of modifications leads to "boundary layer theory" and this group is itself sub-divided into (*a*) "laminar boundary layer theory" and (*b*) "turbulent boundary layer theory." The sub-divisions are of very different character, (*a*) being much more logical in treatment than (*b*).

2. The Assumptions of Boundary Layer Theory.

In many cases of interest in aerodynamics it is assumed—on experimental grounds—that the effect of viscosity on the fluid motion is negligible except in a thin layer on the surface of the moving body and that outside this layer the flow is sensibly that of an inviscid fluid.

It is also normally assumed that direct effects of curvature on the motion in the boundary layer can be neglected, although account is taken of the indirect effect which comes from the effects of curvature on pressure distribution.

The idea and the first formulation of the boundary layer equations for laminar motion is due to Prandtl. In a paper before the R.Ae.S. in November, 1924, I gave a detailed account of the derivation of these equations and showed that the above restrictions convert equations (1.1), (1.2) and (1.3) to

$$q\frac{\partial q}{\partial s}+w\frac{\partial q}{\partial n}=\nu\frac{\partial^2 q}{\partial n^2}-(1/\rho)\,\partial p/\partial s \quad . \quad . \quad . \quad . \quad (2.1)$$

$$0=\partial p/\partial n \quad . \quad . \quad . \quad . \quad . \quad (2.2)$$

and

$$\partial q/\partial s+\partial w/\partial n=0 \quad . \quad . \quad . \quad . \quad (2.3)$$

where q is the velocity of the fluid measured parallel to the surface and w the velocity perpendicular to it; s is a distance measured along the surface and n normal to it. Equation (2.2) shows that, to this order of approximation, the pressure through the boundary layer is constant and may be taken as that on the surface of the body or at the outside of the boundary layer, where Bernoulli's equation holds, *i.e.*, where

$$p+\tfrac{1}{2}\rho\bar{q}^2=\text{const.} \quad . \quad . \quad . \quad . \quad . \quad (2.4)$$

$\bar{q}$ is the velocity at the outer boundary of the layer.

In applying equations (2.1) to (2.4) to a flat plate moving in his own plane Blasius used special co-ordinates; instead of n the variable $n/\sqrt{s}$ was substituted, s being measured from the leading edge. He then found that the stream function multiplied by $\sqrt{s}$ was a function of $n/\sqrt{s}$.

The physical assumption is that the pressure, and thence by (2.4) the velocity, outside the boundary layer is independent of s. On the surface of the plate the velocity is zero.

If $$\epsilon \equiv n/\sqrt{s} \text{ and } \psi_1 = \psi \cdot \sqrt{s} \quad . \quad . \quad . \quad . \quad . \quad (2.5)$$

the equation of motion becomes

$$\psi_1 \frac{\partial^2 \psi_1}{\partial \epsilon^2} = 2\nu \frac{\partial^3 \psi_1}{\partial \epsilon^3} \quad . \quad . \quad . \quad . \quad . \quad (2.6)$$

and the solution is obtained by assuming that

$$\psi_1 = a_0 \epsilon^2 (1 + a_1 \epsilon^3 + a_2 \epsilon^6 + a_3 \epsilon^9 + \ldots) \quad . \quad . \quad . \quad (2.7)$$

Substituting in (2.6) the value given by (2.7) leads to

$$a_1 = (2/\sqrt{5})(a_0/\nu),\ a_2 = (22/8!)(a_0/\nu)^2, \text{ etc.} \quad . \quad . \quad (2.8)$$

There are several solutions of (2.6), one of which was given in detail in R.Ae.S. Journal, January, 1925; $\bar{q}$ being the velocity outside the boundary layer the essential solution is

$$a_0 = -0.166\sqrt{(\bar{q}^3/\nu)} \quad . \quad . \quad . \quad . \quad (2.9)$$

and the shear on the plate is

$$\overline{\partial q \ \partial n}|_{n=0} = 0.332\sqrt{(\bar{q}^3/\nu)} \quad . \quad . \quad . \quad . \quad (2.10)$$

and this leads to a drag coefficient k_D where

$$k_D \equiv \text{resistance}/\rho s \bar{q}^2 = 1.33\sqrt{(\nu/\bar{q}b)} \quad . \quad . \quad . \quad (2.11)$$

b is the dimension of the plate in the direction of the stream.

We are thus led to a Reynolds number $q\bar{b}/\nu$ and this may be applied to any part of the plate, b being replaced by a current co-ordinate s.

More generally this type of Reynolds number has been applied to airship forms, the area used in defining the resistance coefficient k_D being the wetted area up to an axial distance b. The striking result is obtained that drag coefficients for flat plates are in fairly close agreement with drag coefficients for airship models. The agreement holds above and below the critical Reynolds range in which the flow changes from being laminar to being turbulent.

In the transition region, $\bar{q}b/\nu \sim 5 \times 10^5$, other factors such as air stream turbulence lead to very different results in different wind tunnels.

The agreement shown by the flat plate—airship comparison is used to justify the argument that results from one kind of experiment may be applied to others and it may be that in some applications the analogy is pressed too far.

3. Extension of Laminar Boundary Layer Theory to Curved Surfaces.

The next steps in present-day boundary layer theory are probably best given in R. and M. No. 1632, "Steady Flow in the Boundary Layer Near the Surface of a Cylinder in a Stream," by Howarth. A solution of (2.1) to (2.3) is extended from the flat plate to take into account the variations of pressure and velocity due to curved surfaces. What Howarth describes as the "symmetrical case" will serve to illustrate the processes followed.

From observations of pressure distribution—or less precisely from inviscid fluid theory applied to the cylinder—the value of $\bar{q}$ as a function of s is found by use of Bernoulli's equation. The velocity at the outside of the boundary layer is then expressed as well as possible in the form

$$q = q_1 s + q_3 s^3 + q_5 s^5 + \ldots \quad . \quad . \quad . \quad . \quad . \quad (3.1)$$

For small values of s, reckoned usually from the stagnation point, (3.1) presents no difficulties, but for large values modifications of procedure have been found necessary. In the case of the circular cylinder the stream breaks away from the surface at some point near to the maximum diameter and a streamline normal to the surface is formed with a flow somewhat akin to that near a stagnation point. In the theory of maximum lift, shortly to be described, the determination of this point of separation is fundamental; it may be doubted whether the basic assumptions behind (2.1)-(2.3) are valid at the separation point itself. On the other hand, experimental evidence and comparison with

calculation seem to justify those equations until the separation point is nearly reached. Except for the complication involved it would be possible to start as indicated in (3.1) and to continue with the full equations (1.1) to (1.3) by a step-to-step process of calculation. If quick results in a number of cases are desired this suggestion will not be acceptable, but if an explanation of stalling is being sought the extra labour of computation may be considered justifiable.

Using the stream function as defined by

$$q = \partial\psi/\partial n, \quad w = -\partial\psi/\partial s \qquad (3.2)$$

assume

$$\psi = F_1 s + F_3 s^3 + F_5 s^5 + \ldots \qquad (3.3)$$

where F's are functions of n, the normal distance from the surface.

From (3.2) and (3.3) we have

$$q = F'_1 s + F'_3 s^3 + F'_5 s^5 + \ldots \qquad (3.4)$$

and

$$-w = F_1 + 3F_3 s^2 + 5F_5 s^4 + \ldots \qquad (3.5)$$

and using these in the boundary layer equation (2.1) leads to

$$(F'_1)^2 + F_1 F''_1 = q_1{}^2 + \nu F'''_1 \qquad (3.6)$$

$$4F'_1 F'_3 - 3F''_1 F_3 - F_1 F''_3 = 4q_1 q_3 + \nu F'''_3 \qquad (3.7)$$

and so on.

In obtaining (3.6) and (3.7) use of (3.1) has been made, since (3.3) must become (3.1) when the outside of the boundary layer is reached. The differentiations are with respect to n.

Equation (3.6) is a differential equation for F_1, the solution of which will involve q_1 and ν; various writers have shown that it may be transformed to a form which is independent of q_1 and ν, and so a standard solution for all cylinders results. It is this fact which makes the method so attractive.

Equations (3.6) and (3.7) are transformed to achieve this desirable end by using a new variable

$$\eta = (q_1/\nu)^{\frac{1}{2}} n \qquad (3.8)$$

and by writing

$$F_1 = (q_1\nu)^{\frac{1}{2}} f_1, \quad F_3 = 4q_3 (\nu/q_1)^{\frac{1}{2}} f_3 \qquad (3.9)$$

whence it follows that (3.6) is replaced by

$$(\partial f_1/\partial\eta)^2 - f_1 \frac{\partial^2 f_1}{\partial\eta^2} = 1 + \frac{\partial^3 f_1}{\partial\eta^3} \qquad (3.10)$$

with a similar result for (3.7). It will be seen that the changes of variable given by (3.8) and (3.9) have produced a differential equation (3.10) which is independent of q_1 and ν and in which f_1 is a function of η only. The boundary conditions are found by equating (3.4) and (3.1) on the outside of the boundary layer; this comparison gives at once, F_1 and F'_1 zero on the cylinder and $F'_1 = q_1$ at the outside, whence it follows that

$$\left.\begin{array}{l} f_1 \text{ and } \partial f_1/\partial n \text{ are each zero where } \eta = 0 \\ \text{and } \partial f_1/\partial n = 1 \text{ as } n \text{ increases indefinitely} \end{array}\right\} \qquad (3.11)$$

Equation (3.10) with the boundary conditions (3.11) has been solved and Howarth gives a table from which the following has been extracted:—

η	f_1	$\partial f_1/\partial\eta$	$\partial^2 f_1/\partial\eta^2$
0	0	0	1.2326
0.1	0.0060	0.1183	1.1328
0.2	0.0233	0.2266	1.0345
0.5	0.1336	0.4946	0.7583
1.0	0.4592	0.7778	0.3980
1.5	0.8873	0.9161	0.1769
2.0	1.3619	0.9732	0.0658
3.0	2.3525	0.9985	0.0051
4.0	3.3518	1.0000	0.0002

The use of this table quickly leads to the determination of F_1 and its first and second derivatives in any particular problem. Tables are also given by Howarth which similarly lead to F_3, F_5 and F_7, and the method of extension to any number of F's has been developed, but as usual a limit to utility is set by the labour of computation. Additional tables are given for "unsymmetrical cylinders."

I do not propose to consider here the change of method which is required to carry the calculation of the flow in the boundary layer to the point of separation, but will give an illustration to show what can be done. In R. and M. No. 1313 Green gives full details of calculations by another method with corresponding experiments for a circular cylinder.

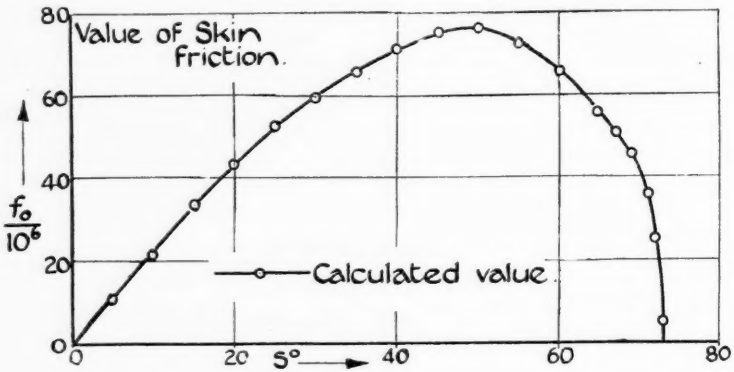

FIG. 1.

Fig. 1 shows the skin friction at various distances along the surface on a base of distance round the cylinder in degrees. It will be seen that the calculations have been carried close to the separation point, which occurs where f_0 or $\partial q/\partial n = 0$ and the various figures in R. and M. No. 1313, which compare calculated and observed velocity distributions in the boundary leave no doubt as to the substantial correctness of the theory (Fig. 2).

In one respect a complete test of theory was not made by Green, since an observed pressure distribution and not a calculated one was used in the calculations for $\bar{q}$.

The separation point was observed by introducing smoke into the stream and we may conclude from all the evidence available that, for the particular Reynolds number chosen, $Vd/\nu \sim 10^5$, calculation on the basis outlined above is sufficiently accurate to determine the flow up to the point of separation.

4. Maximum Lift Coefficient on the Basis of a Laminar Boundary Layer up to the Point of Separation.

Howarth and Kármán have both dealt with this problem in recent papers. The theory involves the possibility of calculation of boundary layer flow up to the point of separation, or rather, up to the two points of separation which are associated with a body either unsymmetrical itself or unsymmetrically placed in the stream of fluid. In addition the lift L on the cylinder is assumed to be connected with the circulation Γ by the formula

$$L = \Gamma \rho V \qquad . \qquad . \qquad . \qquad . \qquad . \qquad (4.1)$$

a formula well established for aerofoils as substantially correct over a large range of angle, but perhaps needing some reservations at or near stalling angle.

The pressure distribution round a cylinder depends on the circulation among other things, and hence the position of the points of separation will depend on the circulation pre-supposed, and the theory of lift involving boundary layer theory requires a criterion for the selection of an appropriate circulation. This criterion is based on the rational hypothesis that the amount of positive vorticity passed into the wake must equal the negative vorticity. If this were not so, the vorticity in the wake would continuously increase, and as a consequence of the connection between vorticity and circulation the lift on the cylinder as defined by (4.1) would also increase continuously.

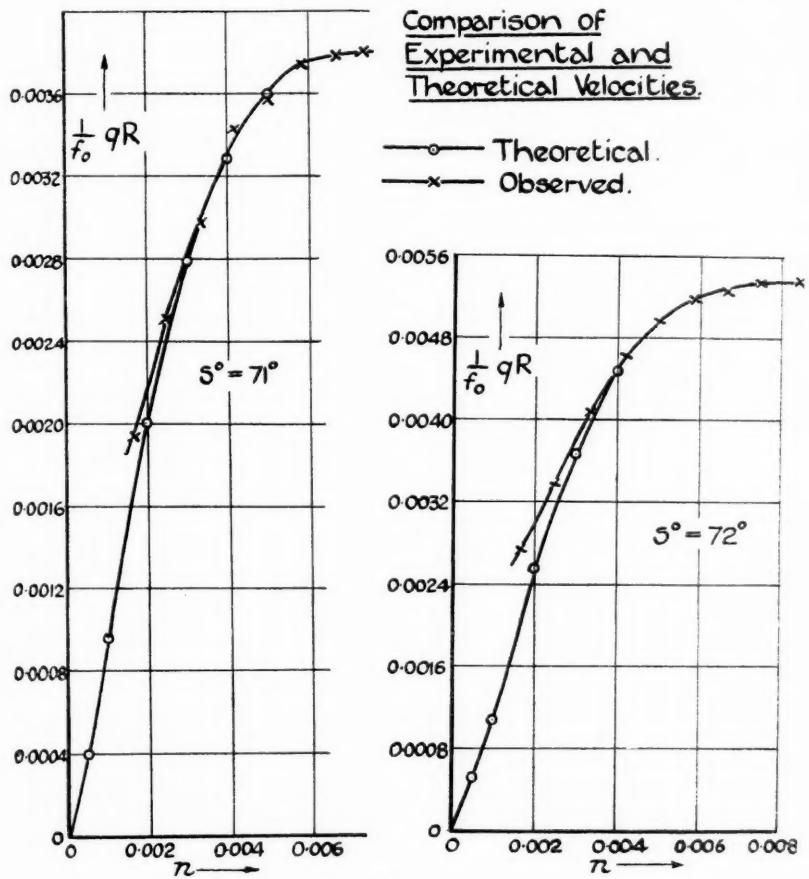

FIG. 2.

Now consider the vorticity which is being generated in the boundary layer; to the order of accuracy retained in the theory the vorticity ζ is equal to $\partial q/\partial n$ and the amount crossing a given section of the boundary layer will be

$$\int_0^\delta q\,(\partial q/\partial n)\,dn = \bar{q}^2/2 \qquad . \quad . \quad . \quad . \quad (4.2)$$

and hence the amount of vorticity passing down the boundary layer is determined by the external velocity at the point or by the pressure. If it be assumed that

there is no creation of vorticity behind the points of separation, *i.e.*, if we assume relatively dead fluid in the wake, it follows that the appropriate circulation round a cylinder can be found by making the pressures at the two points of separation equal to each other. This theorem is attributed to Betz.

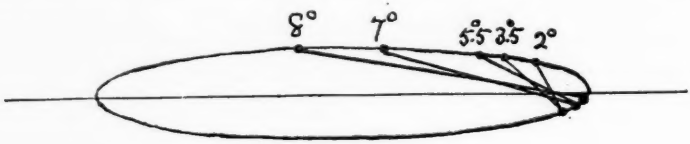

FIG. 3.

Howarth has applied the boundary layer theory as outlined above to the calculation of the lift coefficient of an elliptic cylinder of fineness ratio six to one, and Fig. 3 shows the separation points for inclinations of the major axis of 2°, 3°·5, 5°·5, 7° and 8°, whilst Fig. 4 shows the calculated values of the lift coefficient k_L. Howarth remarks:—" It will be seen that the method considered will find the circulation and velocity distribution appropriate to a small wake, if there is one, since the assumed velocity distribution is obtained by neglecting the size of the wake " (on the basis of inviscid fluid theory). " . . . Hence the rapid increase in the width of the wake given by the method considered is indicative of stalling, and we may say that the elliptic cylinder of fineness ratio six to one stalls at about 7° incidence."

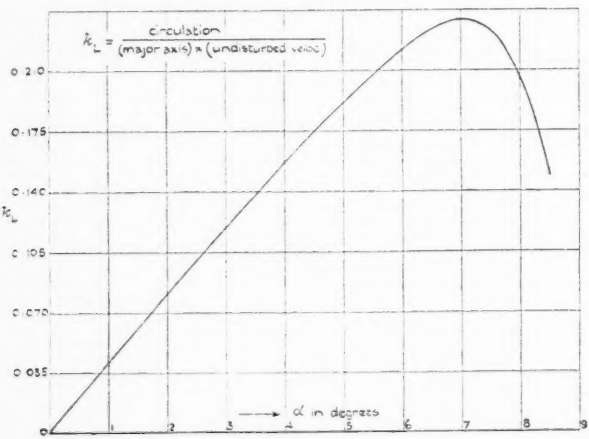

FIG. 4.

" The calculations were made on the assumption of a laminar boundary layer and this limits their application to values of Reynolds number not greater than the order 10^5."

Up to this limit the result is independent of Reynolds number except for the general limitation of the theory to cases of large Reynolds number.

It seems to me that the theory of the laminar boundary layer has much in its favour; it is a process of logical development from step-to-step and the limitations and danger points are clearly indicated. Some remarks on the corresponding lift coefficient theorems for turbulent flow will be given later, but it may be said here that they do not inspire the measure of confidence I have been able to give to the laminar theory.

5. Turbulent Boundary Layers.

The connection between the equations of motion of a viscous fluid and those applied in turbulent motion theory is often very slight; one of the more direct arguments due to Reynolds seems to me to make a good starting point. The usual theories are statistical and are concerned only with averagely steady motions; fluctuations of velocity are presumed to occur so quickly that a correct average is attained with a very short total time. Reynolds starts with the equations of motion in the form

$$\left.\begin{aligned}\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}&=(1/\rho)\{\partial p_{xx}/\partial x+\partial p_{yx}/\partial y\}\\ \frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}&=(1/\rho)\{\partial p_{yy}/\partial y+\partial p_{xy}/\partial x\}\end{aligned}\right\} \quad . \quad . \quad (5.1)$$

$$\left.\begin{aligned}\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}&=(1/\rho)\{\partial p_{yy}/\partial y+\partial p_{xy}/\partial x\}\end{aligned}\right\} \quad . \quad . \quad (5.2)$$

and the equation of continuity (1.3).

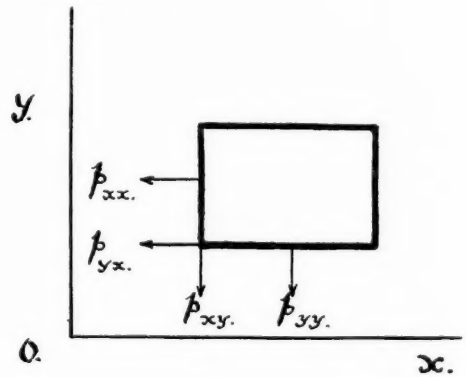

Fig. 5.

The pressures p_{xx} and p_{yy} are normal pressures, whilst the shear pressures characteristic of viscous fluid motion are denoted by p_{yx} and p_{xy}. Equations (5.1) and (5.2) take the better known forms (1.1) and (1.2) by virtue of the relations

$$\left.\begin{aligned}p_{xx}&=-p+2\mu\frac{\partial u}{\partial x}\\ p_{yy}&=-p+2\mu\frac{\partial v}{\partial y}\\ p_{xy}&=p_{yx}=\mu\,(\partial v/\partial x+\partial u/\partial y)\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (5.3)$$

Using the equation of continuity, Reynolds rewrote (5.1) as

$$\rho\frac{\partial u}{\partial t}=(\partial/\partial x)\,(p_{xx}-\rho u^2)+(\partial/\partial y)\,(p_{yx}-\rho uv) \quad . \quad . \quad . \quad (5.4)$$

and then proceeded to apply the idea that the velocities u and v and the pressure p could be expressed in the form

$$u=\bar{u}-u',\ v=\bar{v}+v',\ p=\bar{p}+p' \quad . \quad . \quad . \quad . \quad (5.5)$$

where u', v' and p' represent the fluctuations of velocity and pressure about the mean values $\bar{u}$, $\bar{v}$ and $\bar{p}$. In other words,

$$(1/T)\int_0^T u'dt,\ (1/T)\int_0^T v'dt \text{ and } (1/T)\int_0^T p'dt \quad . \quad . \quad (5.6)$$

are all presumed zero for a sufficiently large value of T.

A quantity such as u^2 can now be expanded as

$$u^2 = \bar{u}^2 - 2\bar{u}u' + u'u' \quad . \quad . \quad . \quad . \quad (5.7)$$

and as a result of averaging we are left with

$$u^2 = \bar{u}^2 + \overline{u'u'} \quad . \quad . \quad . \quad . \quad . \quad (5.8)$$

where $\overline{u'u'}$ represents the average value of $u'u'$.

Similarly

$$uv = \bar{u}\bar{v} + \overline{u'v'} \quad . \quad . \quad . \quad . \quad . \quad (5.9)$$

and (5.4) can now be written in the form

$$\rho \frac{\partial \bar{u}}{\partial t} = (\partial/\partial x)(\bar{p}_{xx} - \rho\bar{u}^2 - \rho\overline{u'u'}) + (\partial/\partial y)(\bar{p}_{yx} - \rho\bar{u}\bar{v} - \rho\overline{u'v'}) \quad . \quad (5.10)$$

This differs from the form of the exact equation by the terms $-\rho\overline{u'u'}$ and $-\rho\overline{u'v'}$ in the normal and shear pressures. Turbulence may therefore be regarded as producing effects equivalent to a change in the normal and shear pressures. In much of the literature of the subject the change of shear pressure is taken as a fundamental starting point.

Since a great many deductions are drawn from experiments in circular pipes the equations of motion for that case will be quoted. If q' and s' be the radial and tangential components of the turbulent velocity the equations are

$$0 = \partial\bar{p}/\partial x + (\mu/r)(\partial/\partial r)(r\partial\bar{u}/\partial r) - (\rho/r)(\partial/\partial r)(r\overline{u'q'}) \quad . \quad (5.11)$$

and

$$0 = -\partial\bar{p}/\partial r - (\rho/r)(\partial/\partial r)(r\overline{q'q'}) + (\rho/r)\overline{s's'} \quad . \quad . \quad (5.12)$$

Equation (5.12) shows that $\partial\bar{p}/\partial r$ is not necessarily zero in turbulent motion, but this is commonly taken to be a legitimate interpretation of experiments and to the same degree of accuracy it follows that $\overline{q'q'}$ and $\overline{s's'}$ are unimportant. On the other hand, $\overline{u'q'}$ has a marked effect on the solution of (5.11); the distribution of velocity at large Reynolds numbers is far from the parabola which accounts for flow below the critical velocity and which would follow from (5.11) if $\overline{u'q'}$ were put equal to zero.

Stanton* found for a rough pipe giving a resistance proportional to the square of the speed over a considerable range of Reynolds number that, over a circle 0.9 of the maximum radius, the velocity distribution could be expressed as a parabola, and this gives support to Boussinesq's hypothesis that the existence of turbulence is equivalent to a new coefficient of viscosity over most of a pipe. The conditions at the wall are of great importance and are not covered by the above idea of a "mechanical viscosity."

Equation (5.1) is easily integrated with respect to r to get

$$\overline{u'q'} = \nu\partial\bar{u}/\partial r - (r/2\rho)(\partial\bar{p}/\partial x) \quad . \quad . \quad . \quad . \quad (5.13)$$

From Stanton's† experiments we also know that, whether the motion be laminar or turbulent the conditions at the surface of a pipe are satisfied by

$$\nu\partial\bar{u}/\partial r|_{\text{wall}} = (r_0/2\rho)(\partial\bar{p}/\partial x) \quad . \quad . \quad . \quad . \quad (5.14)$$

and hence by comparison with (5.13), it follows from experiment that $\overline{u'q'}$ is zero on the wall. In the central part of the pipe $\nu\partial\bar{u}/\partial r$ is not very important, and it follows from (5.13) that $\overline{u'q'}$ is proportional to r, the distance from the axis. Equation (5.13) is often reduced to the form

$$\overline{u'q'} = -(r/2\rho)(\partial\bar{p}/\partial x) \quad . \quad . \quad . \quad . \quad (5.15)$$

and it follows that the known conditions at the wall are being ignored and an approximation of uncertain value results.

* Proc. Roy. Soc., A, Vol. **85** (1911).
† Proc. Roy. Soc., (1920).

The following comments by G. I. Taylor indicate clearly the speculative nature of the theories now to be described:—

"These considerations have led me now to publish a result which I obtained 21 years ago and gave in an essay for which the Adams Prize was awarded in 1915. At that time, when I first discovered the vorticity transport theory of turbulent motion, I had to make certain assumptions in order to be able to discuss the flow in a pipe, and these assumptions seemed for many years so speculative that I did not pursue the matter beyond making the calculation . . . to predict the distribution of velocity in a pipe.

"In the intervening years, however, the assumptions which I regarded as too speculative for publication have been made by others and generally accepted. . . ."

It will be understood, therefore, that I am in some measure absolved from endorsing some of the succeeding arguments.

6. Karman's Theory of Turbulence.

Kármán considers the two-dimensional motion of a fluid, the mean motion being uniform and parallel to the axis of X. An observer at P is presumed to move with the mean velocity of the fluid and to observe fluctuations so far as they depend on shear and rate of shear of the mean motion and turbulence. The basic assumption is that the observer then sees all that matters.

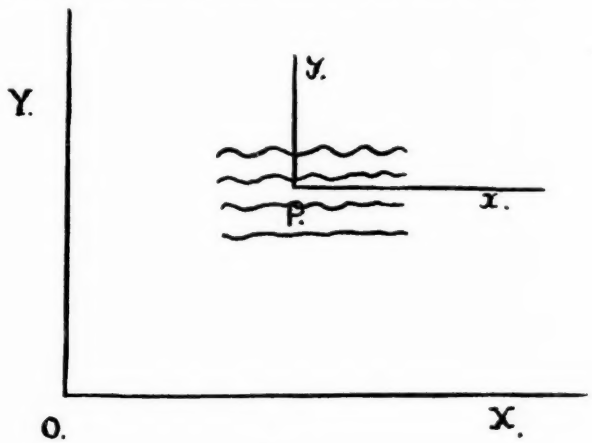

Fig. 6.

Subtracting the mean velocity $\bar{u}$, Kármán writes for the remainder of the velocity:—

$$\left.\begin{array}{c} u=\overline{\partial\bar{u}/\partial y}|_P\, y+\overline{\partial^2\bar{u}/\partial y^2}|_P\,(y^2/2)+u' \\ \text{and } v=v' \end{array}\right\} \quad . \quad . \quad . \quad (6.1)$$

where u' and v' refer to the turbulent components of velocity. In order to develop a similarity criterion, write:—

$$\left.\begin{array}{ll} x=l\xi_1, & y=l\eta, \\ u'=Au'_1, & v'=Av'_1, \\ u=Au_1, & v=Av_1, \end{array}\right\} \quad . \quad . \quad . \quad . \quad (6.2)$$

where l and A are constants—presumably for all fully developed turbulent motions. Combining (6.1) and (6.2) we get

$$\left.\begin{array}{c} Au_1=\overline{\partial\bar{u}/\partial y}|_P\, l\eta+\overline{\partial^2\bar{u}/\partial y^2}|_P\,(l^2\eta^2/2)+Au'_1 \\ Av_1=Av'_1 \end{array}\right\} \quad . \quad . \quad (6.3)$$

Since the purpose of the investigation is to find velocities u_1, v_1, u'_1 and v'_1, which are functions of η and ϵ_1 only, make the multipliers of (6.3) proportional to each other, *i.e.*, write:—

$$A \text{ varies as } l\overline{\partial\bar{u}/\partial y}|_P \text{ varies as } l^2\partial^2\bar{u}/\partial y^2 \quad . \quad . \quad . \quad (6.4)$$

i.e.,

$$l \text{ varies as } \overline{\partial\bar{u}/\partial y}/\overline{\partial^2\bar{u}/\partial y^2}|_P \quad A \text{ varies as } l\overline{\partial\bar{u}/\partial y}|_P \quad . \quad (6.5)$$

The above treatment is not Kármán's; it has been pointed out by Prandtl that other lengths would be defined by taking additional terms in the steady motion derivatives of (6.1) and that Kármán's hypothesis is only one of the simplest that can be made; it has, however, the usual characteristics of small oscillation theorems.

Velocity Distribution for Turbulent Motion in Circular Pipes.

Without assuming any special merits for Kármán's hypothesis by comparison with those of Taylor and Prandtl, use will be made of it for purposes of continuity in the calculation of the velocity distribution in a circular pipe.

If τ be the shear stress at radius r, the resistance of unit length of cylinder of fluid will be $2\pi r\tau$. The force overcoming this resistance is the pressure drop over unit length multiplied by the cross-sectional area of the cylinder, and this is equal to $-\pi r^2\partial p/\partial x$. Hence, we have

$$\tau = -(r/2)\,\partial p/\partial x \quad . \quad . \quad . \quad . \quad . \quad (6.6)$$

the bars over the letters being omitted.

Comparing (6.6) with (5.13) shows that

$$\tau = \rho\overline{u'q'} \quad . \quad . \quad . \quad . \quad . \quad (6.7)$$

to the degree of approximation involved in deducing (5.13). Using (6.3) then gives at once

$$\tau \text{ varies as } \rho A^2 \text{ varies as } \rho^2\,(\partial u/\partial y)^2\,l^2 \quad . \quad . \quad (6.8)$$

and substituting for l^2 from (6.5) leads to

$$\tau = k_1\rho\,(\partial u/\partial r)^4/(\partial^2 u/\partial r^2)^2 \quad . \quad . \quad . \quad . \quad (6.9)$$

where k_1 is at present undetermined.

If τ_0 be the shear on the wall, equation (6.6) gives

$$\tau_0 = -(r_0/2)\,(\partial p/\partial x) = (r_0/r)\,\tau \quad . \quad . \quad . \quad . \quad (6.10)$$

and equation (6.9) may be written in the form

$$(\partial^2 u/\partial r^2)/(\partial u/\partial r)^2 = (1/\sqrt{r})\sqrt{(k_1\rho r_0/\tau_0)} \quad . \quad . \quad . \quad (6.11)$$

Integrate with respect to r to get

$$-1/(\partial u/\partial r) = 2\,(\sqrt{r} - \sqrt{a})\sqrt{(k_1\rho r_0/\tau_0)} \quad . \quad . \quad . \quad (6.12)$$

where "a" is a constant of integration. Integrating again leads to

$$u_{\max} - u = -\sqrt{(a\tau_0/k_1\rho r_0)}\,\{\log[1 - \sqrt{(r/a)}] + \sqrt{(r/a)}\} \quad . \quad (6.13)$$

Three conditions should be satisfied by u if physical requirements are to be complied with. On the wall of the pipe $u=0$ and its first derivative satisfies the relation $\partial u/\partial r = \tau_0/\mu$; at the centre of the pipe $\partial u/\partial r = 0$. The constant "$a$" can be adjusted to meet either of the wall conditions, but two physical requirements remain unsatisfied.

The check applied to (6.13) is empirical and the constant k_1 is determined in such a way as to agree with experiment (Fig. 7).

Taylor and Goldstein give different formulæ and all differ from experimental formulæ suggested by Stanton and Nikuradse. All the theories leave one or more arbitrary constants to be determined empirically, and over the central region of the pipe the final deductions as to velocity distribution are in fair agreement with experimentally determined distributions.

BLASIUS'S LAW FOR LESS FULLY-DEVELOPED TURBULENCE.

From Nikuradse's experiments as applied to flow in smooth pipes (Fig. 8) Blasius showed that the resistance can be expressed as

$$\lambda \equiv 8\tau_0/\rho u_0^2 = 0.316\,(u_0 d/\nu)^{-\frac{1}{4}} \quad . \quad . \quad . \quad . \quad (6.14)$$

over a range of $R \equiv u_0 d/\nu$ from about 2,500 to 10^5. Stanton's observations show that (6.14) is only an average representation and that the index of R changes markedly over the region to which (6.14) is usually applied.

Blasius rewrote (6.14) as

$$u_0/\sqrt{(\tau_0/\rho)} = 6.33\,[(d/\nu)\sqrt{\tau_0/\rho}]^{1/7} \quad . \quad . \quad . \quad (6.15)$$

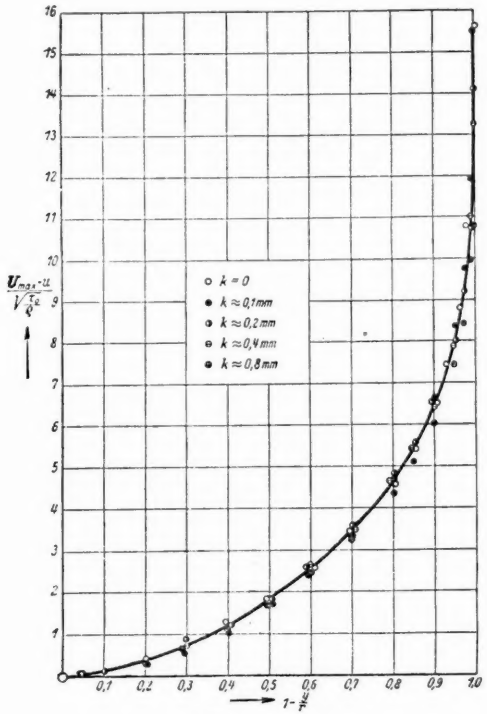

FIG. 7.

The next step is, I think, difficult to justify. Assume a velocity distribution of the form

$$u = K\,(d/2 - r)^n \quad . \quad . \quad . \quad . \quad . \quad (6.16)$$

and by integration find the mean velocity u_0 as

$$u_0 = (2u_{max})/(n+1)(n+2) = \{\,2K/(n+1)(n+2)\,\}\,(d/2)^n \quad . \quad (6.17)$$

and identify this with (6.15). n is seen to be $1/7$ and the determination of K gives for (6.16) the final result

$$u = 8.55\sqrt{(\tau_0/\rho)}[\,\{\,d/2 - r)/\nu\,\}\,\sqrt{(\tau_0/\rho)}]^{1/7} \quad . \quad . \quad (6.18)$$

a formula which indicates that u varies as the one-seventh power of the distance from the wall.

Fig. 9 shows a comparison by Burgers for a flat plate, and it is obvious from this and from Stanton's experiments that the law is far from good near the walls.

For fully developed turbulence some such formula as (6.13) is used instead of (6.18).

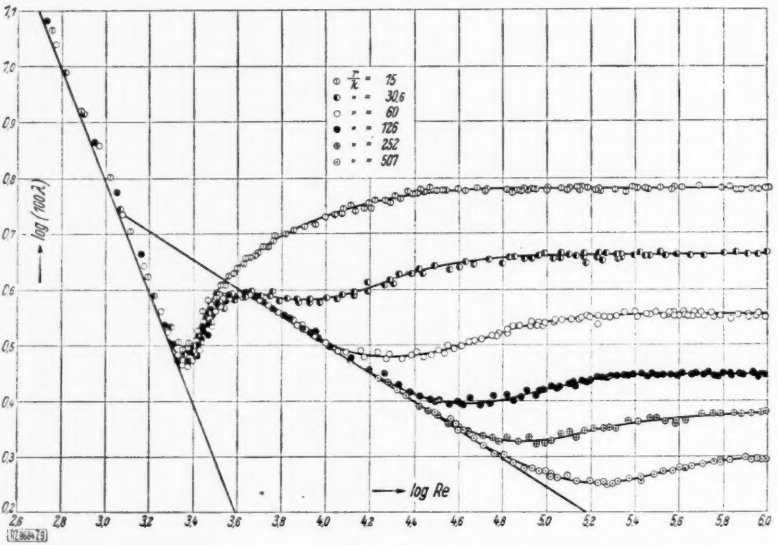

FIG. 8.

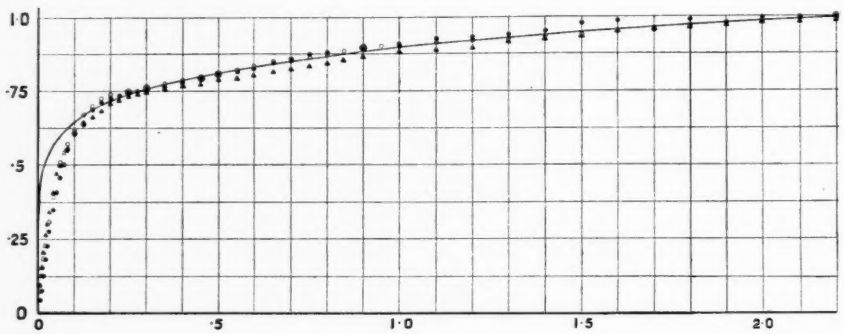

FIG. 9.

The curve is $u/u_0=(y/2.20)^{1/7}$.

Burgers & Zignen. Delft 1921.

7. TURBULENT BOUNDARY LAYER THEORY.

As for laminar boundary theory it is assumed that the change from zero velocity on the surface to the free velocity of the fluid takes place in a thin layer. Outside this layer the fluid is treated as though inviscid and the pressure round a body—such as an aerofoil—is calculated for an infinitely thin layer. Bernoulli's equation connects the pressure on the body with the velocity at the outside of the boundary layer.

For similar bodies it is strictly true that at similar points the surface traction τ_0 can be related to other quantities of importance by the relation

$$\tau_0 = \rho u_0^2 f(u_0\delta/\nu) \quad . \quad . \quad . \quad . \quad . \quad (7.1)$$

and that the velocity u in the boundary layer can be related to the velocity u_0 at its outer limit by a formula

$$u/u_0 = F(y/\delta) \quad . \quad . \quad . \quad . \quad . \quad (7.2)$$

where y is distance from the surface and f and F are two functions normally known only by experiment, but deducible approximately by the theories referred to in previous sections.

In order to obtain a general theorem the assumption is made that f and F are independent of the shape of the body over which the motion takes place. A further assumption—not fundamentally necessary—is that f and F may be taken from experiments in pipes. Better results would probably follow if the standard functions were taken on some form of body not greatly differing from that under investigation. It may be argued that this is very near to empiricism to which my reply would be that the answer would be appreciably nearer the truth.

In order to apply (7.1) and (7.2) in a particular case a further theorem is required connecting τ_0 and δ, and this is obtained by considering the balance of pressures and momentum for an element of the boundary layer.

Consider an element of fluid ABCD near a cylindrical surface. Take A as origin with an axis of S along the surface and an axis of y normal to it. DC will be taken as part of a streamline so far from the surface as to be outside the boundary layer. The steps, of a familiar character, lead to the equation

$$(\partial/\partial s)\int_0^\delta u(u_0-u)\,dy + (\partial u_0/\partial s)\int_0^\delta (u_0-u)\,dy = \tau_0/\rho \quad . \quad . \quad (7.3)$$

and we can now proceed to Prandtl's application to turbulent flow for a smooth flat plate.

RESISTANCE OF A SMOOTH FLAT PLATE FOR TURBULENT MOTION.

The flow is supposed to take place in the region for which the 1/7th power law applies, *i.e.*,

$$u/u_0 = (y/\delta)^{1/7} \quad . \quad . \quad . \quad . \quad . \quad (7.4)$$

In a circular tube the maximum velocity is reached at the centre and the thickness of the boundary layer is regarded as $d/2$. Equation (6.14) then becomes

$$\tau_0 = 0.0234\,\rho u_0^2 (u_0\delta/\nu)^{-\frac{1}{4}} \quad . \quad . \quad . \quad . \quad (7.5)$$

The usual assumption is made that for a flat plate $\partial u_0/\partial s = 0$ and (7.3) then becomes

$$(\partial/\partial s)\int_0^\delta u(u_0-u)\,dy = \tau_0/\rho \quad . \quad . \quad . \quad . \quad (7.6)$$

which combined with (7.4) leads to the relation

$$(7/72)\,u_0^2\,(\partial/\partial s)\,\delta = \tau_0/\rho \quad . \quad . \quad . \quad . \quad (7.7)$$

Now equate to (7.5) so as to eliminate τ_0 to get

$$(\partial/\partial s)\,\delta = 0.240\,(u_0\delta/\nu)^{-\frac{1}{4}} \quad . \quad . \quad . \quad . \quad (7.8)$$

which by integration gives

$$\delta = 0.382\,s\,(\nu/u_0 s)^{1/5} \quad . \quad . \quad . \quad . \quad (7.9)$$

and a resistance for one side of the plate

$$\text{Resistance} = 0.037\,s\,(\nu/u_0 s)^{1/5}\,\rho u_0^2 \quad . \quad . \quad . \quad (7.10)$$

A similar calculation based on Kármán's theory for fully developed turbulence gives the formula

$$1/\sqrt{C_f} = 1.7 + 4.15 \log_{10} (R_x C_f) \quad . \quad . \quad . \quad (7.11)^*$$

where C_f is a resistance coefficient.

$$C_f = \text{resistance}/\tfrac{1}{2}\rho U_0^2 S = 2k_D \quad . \quad . \quad . \quad . \quad (7.12)$$

$R_x = U_0 x / \nu$ where x is the distance down the plate in the direction of motion and S is the area of surface under consideration.

8. Maximum Lift Coefficient for Turbulent Boundary Layers.

The difference of procedure in dealing with turbulent boundary layers and laminar layers has been indicated in some detail in the case of the flat plate, and a similar procedure applied to curved surfaces leads to an estimate of lift coefficient on the same principles for both turbulent and laminar boundary layers. The basic equation is now (7.3) which covers velocity variations at the outside of the boundary layer. As for the flat plate, the variation of velocity in the boundary layer is taken from experiment and the calculation of the surface traction at any point on the surface follows as for the flat plate, except that τ will become zero in the general case of a cylinder. Now $\tau = 0$ is the same condition as $\partial q/\partial n = 0$ on the surface and hence determines the separation point. The procedure in other respects is like that for laminar flow, the circulation being changed until the pressures at the upper and lower separation points are the same. Fig. 11 gives Howarth's results for an elliptic cylinder of fineness ratio 6 : 1.

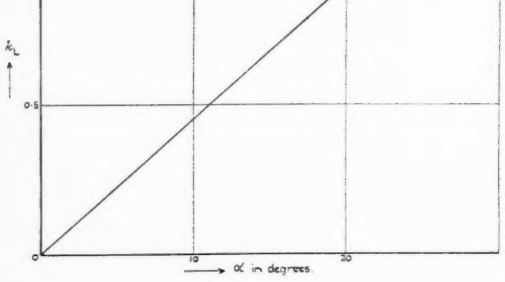

Fig. 11.

Whatever may be thought of the details of the calculations it seems to me that the reason for stalling is more clearly indicated than before the calculations were made.

I will conclude this section by quoting from authors the desirability of caution in drawing conclusions from turbulent boundary layer theory :—

In a paper by Kármán and Millikan on "A Theoretical Investigation of Maximum Lift Coefficient" the remark is made :—"The extension of the present theory so as to obtain valid results for large values of Reynolds number and lift coefficient depends on the development and application of a satisfactory theory of the separation characteristics of a turbulent boundary layer and such a theory has, unfortunately, not yet been developed."

Howarth says :—"Until a rational theory, which gives the velocity distribution through the boundary layer and the corresponding skin friction is evolved, we must rely on two empirical relations. . . ."

* Journal of the Aeronautical Sciences, January, 1934. Th. von Kármán.

ARGUMENT FROM EXPERIMENT TO EXPERIMENT.

It follows from the general theory of turbulent motions as it now exists that arguments from experiment to experiment are made both qualitatively and quantitatively and only in the latter case is recourse to computation necessary. Some recent results of experiments on aerofoils with roughened surfaces in the compressed air tunnel at the N.P.L. are an illustration of this general similarity.

The general form of the curves found for the aerofoil is also that for pipes as will be seen by comparing Figs. 12 and 8.

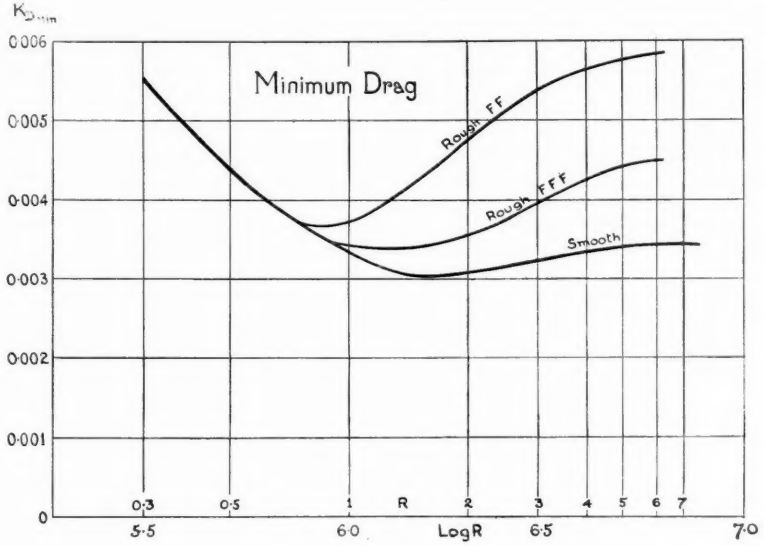

FIG. 12.

It seems to me that much will presently be possible in dealing theoretically with changes from one body to another and that analytical methods will give place to computation and greater accuracy. One of the important results of the analytical methods is the establishment of the main lines of enquiry and for this a lower degree of physical requirements may well be accepted.

DISCUSSION.

Dr. E. G. RICHARDSON: Professor Bairstow has dealt so critically with boundary layer theories, pointing an unerring finger at their weak points, that one finds little to comment on in his interesting paper. He would, however, like to endorse his remarks on the nth power velocity assumption which appears, a *deus ex machina*, in the middle of the argument of the turbulent boundary layer of Prandtl and Blasius. Further deduction that $n=7$ from the experiments seems difficult to justify. He had tried plotting Nikuradse's pitot tube results —as well as some of his own hot wire results—for the velocity gradient across a pipe in turbulent flow, on a logarithmic basis, and his conclusion is that n could be anything from 6 to 10 within the limits of experimental error. On the other hand, he would like to suggest that the agreement between Blasius' theory for the thin plate and Burgers' experiments is actually better near the plate than Fig. 9 shows, as the hot wire readings of Zijnen on which the experimental results are based were over-corrected for proximity of the plate.

Dr. N. A. V. PIERCY (*Fellow*): He could scarcely imagine a paper more interesting, more timely and more clearly and convincingly put than that by Professor Bairstow.

Commenting on the first part of the paper, he said there were some people who held that there was so much turbulence that the study of streamline flow was rather a waste of time; others, however, with whom he associated himself, entirely disagreed with that view. He believed they were in the midst of a very rapid development; it was even conceivable that within a year or two the various incomprehensible equations—as they had been called, with some feeling—would have lost their sting in one respect, and that was in connection with two-dimensional flow, in not too difficult cases. But was that enough? It seemed to him that the three things—the monoplane, the variable-pitch airscrew and increased speed range—had conspired together to bring about a decline of aspect ratio so that the modern aeroplane resembled nothing so little as a two-dimensional body. Did one really glean any real confidence from the airship experiments quoted in the paper? They knew that in truly laminar flow—*i.e.*, when laminæ *were* laminæ—skin friction was greatly affected by the form of the transverse contour, and experiments seemed to suggest that in turbulent flow the same thing happened, though to a less marked extent. He would like to see a start made on three-dimensional steady boundary layers, if somebody could find a reasonably simple method. That departure seemed most necessary. It appeared to him to be several degrees worse to attempt to calculate—and one needed to calculate accurately—skin friction on wetted surfaces than to pin one's faith to hydraulic mean depth in another branch of engineering.

After intimating that he would communicate further comments in writing, Dr. Piercy expressed his admiration for some of the results shown. The last one, he said, showed a matter which was part and parcel of and intimately concerned with boundary layer theory, which was considerably affecting practical aircraft construction.

Dr. C. M. WHITE (Imperial College): In general no exception could be taken to the author's critical attitude towards the present state of turbulent boundary layer theory. But he seemed perhaps a little too severe in connection with the use of pipe data for determining the function $u/v_0 = F(y/\delta)$ equation (7.2).

Certainly the example quoted in the paper of the use of the 1/7th power law did appear to involve too big a jump, but then this was probably one of the earliest of the attempts to link up the motion in pipes with that in a boundary layer.

The more recent work of Nikuradse on pipes provided two nearly independent numerical constants in a form presumably applicable to other problems. The first of these constants was conveniently written as:—

$$(l/y)\sqrt{(\tau_0/\tau)} = 0.4$$

l being defined by equation (6.8) of the paper. The second constant was linked with the first, which was obviously untenable when $y \to 0$, unless, following Prandtl, the origin for y were shifted by a small amount. Nikuradse's second constant, namely, this shift of origin was:—

$k/34$ for a rough surface of grain size k

or

$(1/q)\ (\mu/\rho V_s)$ for a smooth surface.

These constants would surely still be of the same order if the motion were that in a boundary layer instead of in a pipe.

In applying the pipe results to a boundary layer one did not actually state that the velocity distribution must be the same, but assumed that the two numerical constants mentioned were applicable to both problems. Admittedly this led to the same velocity distribution, but then this was not so far from the truth. The assumption was essentially that one could sufficiently define the turbulent motion at a point near the wall producing it, by defining, (*a*) the shear stress at that

point, (*b*) the distance of the point from the wall, and (*c*) the motion at the wall itself. Did Professor Bairstow demand more terms than these, if so one must despair of ever obtaining a usable theory?

If one accepted that the motion was sufficiently defined by the above three conditions, then, with the aid of Nikuradse's constants, there was no particular difficulty in integrating equation (7.3) of the paper, and the resistance of a rough flat plate of length X could be predicted as approximately:—

$$\sqrt{(X/\delta^{xx})} = 4.65 \log (X/k) + 1.5$$

when X/k exceeded 100 and δ^{xx} was defined by, drag $= \rho U_o^2 B \delta^{xx}$, B being the breadth of the plate.

Experiments made by Dr. Moyal in the Civil Engineering Laboratory of the Imperial College confirmed this in a very satisfactory manner. Various sanded plates were used and the range covered was from $X/k = 10$ to $X/k = 1{,}000$. The experiments gave:—

$$\sqrt{(X/\delta^{xx})} = 4.65 \log (X/k) + 1.0,$$

Valid from $X/k = 10$ up $X/k = 30{,}000$ or more.

It may be said that the discrepancy between predicted and observed values in no case exceeded possible experimental errors.

Incidentally Dr. Moyal's work with pitot tubes showed that throughout the boundary layer the value of $(l/y)\sqrt{(\tau_o/\tau)}$ was of the same order as that obtained by Nikuradse.

From an engineering point of view it was important to know how far it paid to reduce surface roughness; to know approximately what was the maximum size of irregularity which could be neglected. A convenient, though crude, definition followed from the resistance laws given above, since by comparison with the Kármán law (7.11) for smooth surfaces, viz.,

$$\sqrt{(X/\delta^{xx})} = 5.86 \log (\rho U_o \delta^{xx}/\mu) + 4.1,$$

it was seen that the smooth law would give greater resistance when the irregularities were less than a certain size. There was obviously no point in reducing the roughness below that value at which both laws give the same resistance.

To return to the main question of the validity of such treatments, it seemed that all simple theories purporting to represent complicated motions, must involve assumptions, particularly so in their early stages. Everyone would agree with Professor Bairstow in desiring more rigid treatments, but in the meantime let them give due praise to methods which did at least solve some of the problems.

Dr. G. V. Lachmann (*Fellow*): Most designers had suspected that the smoothness of the skin became of greater importance as the speed and size of aircraft increased; they knew now that the skin must be as smooth as possible for very fast aircraft. There were still certain practical difficulties, of course, in securing absolute smoothness. The investigations of Prandtl and Schlichting showed that there was a very small laminar boundary layer between the actual surface and the turbulent layer, and that if the excrescences on the skin did not extend into the turbulent layer they did not cause harm. On a skin-covered wing it was very difficult to avoid certain small grooves where pleats occurred, and from the practical point of view it was very difficult and expensive to fill in those very small grooves and indentations. He was anxious to know to what extent those little irregularities mattered, and he suggested that in the exploration of the problem it was not sufficient to test small models, with carborundum on the surface, in the compressed air tunnel. Such tests would give certain qualitative results, but he wondered whether tests could be carried out at sufficiently high Reynolds numbers ($= 30 \times 10^6$) on surfaces which actually represented the way in which the skin was made up.

Dr. J. W. Maccoll (*Associate Fellow*): The most admirable summary given in the paper of the present situation in regard to the boundary layer theory did not lend itself to very great criticism. However, having been more interested recently in the theory of compressible rather than incompressible fluids, perhaps

he might be allowed to use this occasion for a brief reference to boundary layers in compressible fluids. That the subject of compressibility had become of importance would be realised when it was remembered that a military aeroplane, when diving at 370 m.p.h., was already travelling at half the speed of sound, and therefore, the relative motion of the air near the planes might be quite near the speed of sound. At such a speed the compressibility of the air must affect the properties of the boundary layer, and it would be very useful if some of the university students, and others, began to take an interest in the compressibility of the boundary layer. Such an investigation was not impossible, as would be realised when one studied the literature on the subject; two or three papers* had already been written on the question in Germany, and experimental work was being carried on there. Professor Prandtl had made some measurements in pipes at speeds close to the speed of sound, and such results should give some idea of the boundary layer properties near the speed of sound.†

Finally, Dr. Maccoll congratulated the Society upon having secured Professor Bairstow's admirable résumé of the subject.

Mr. V. M. Falkner (*Associate Fellow*): While appreciating that Professor Bairstow was not very satisfied with the methods in use for dealing with turbulent boundary layers, he asked what he would consider to be the most profitable line of attack for research workers to adopt. Should they turn out a large volume of work, making the assumptions indicated in the paper, or should they do a lesser amount of work by more rigid methods? If the latter, it would be helpful to know what line of attack Professor Bairstow would suggest.

Mr. F. G. Evans (*Associate Fellow*): Had any work been done on the problem of the boundary layer over a heated surface? Although this was a question which had not been dealt with in the paper, he suggested that perhaps an extension of Dr. Maccoll's work on compressibility might be possible. He appreciated that the problem was already awkward enough without introducing temperature differences, but information on this aspect of the subject might be useful and of importance in regard to surface radiators, and so on.

Mr. A. Fage (*Fellow*): There had been many investigations on boundary layer flow, both theoretical and experimental, during the last 25 years, and he considered that Professor Bairstow had been wise in restricting his paper to one particular aspect of this subject. The aspect selected—a survey of the subject from the equations of motion to calculations of profile drag and lift—was very important from the practical standpoint. The purpose of the paper, as he understood it, was to show that whereas the theory of the laminar boundary layer rested on a sound physical basis and was well within the scope of mathematical ingenuity, the same could not be said about the theory of the turbulent boundary layer. One merit of the paper was Professor Bairstow's invitation to investigators to halt for a moment and to consider the physical aspects of turbulent boundary layer theories. Mr. Fage admitted that he had found it difficult to understand the significance of some of the physical assumptions made in turbulent boundary layer theories; but he thought the authors of those theories were well aware of such shortcomings. Nevertheless, it must be realised that the theories had led to very valuable results, and he believed the reason was that they served as connecting links, the empirical constants being obtained from experimental results. Provided the link was not too long, it seemed to him to be very unlikely that one would not be able to predict results in fairly good agreement with practice. It appeared that some of the tests that had been undertaken to assess the relative merits of the theories of turbulent flow were not always very crucial.

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* See, for instance, the treatment of the laminar layer on a flat plate by Busemann: Zeits angew Math. Mech., Vol. 15, p. 23, 1935.

† Some of this work has now been described by Frössel: Forschung, Vol. 7, p. 75; March, 1936.

Referring to the distribution of velocity in a pipe, he said he had tried to obtain the parabolic relation mentioned by Professor Bairstow from Stanton's observations and from his own observations, but without success. Presumably, what Stanton meant was that the distribution was roughly parabolic, and that was rather an important point, because in the theories of turbulence use was made of velocity derivatives. It seemed that the prediction from pipe results of the effect of surface roughness on the drag of wings and flat plates, could be made without theories of turbulent boundary layer. The predictions could be made by dimensional analysis; the controlling parameters being the frictional velocity at the surface, the kinematic viscosity, and the height, shape, and arrangement of the surface excrescences.

Professor Bairstow's paper was rather provocative, in the best sense of the word; and that fact added enormously to the value of the paper.

Mr. H. B. SQUIRE (*contributed*): In the section dealing with turbulent flow no mention is made of the laminar sub-layer near a fixed surface past which fluid is flowing. The existence of this layer was discovered experimentally by Stanton; it may also be deduced from the fact that the Reynolds shear stress—$\rho u'v'$ vanishes at a wall, since v' is zero there, and hence the shear stress can only be transmitted to the wall by the agency of viscosity. Taking this layer into account removes the apparent difficulty in making Kármán's solution for the velocity distribution in a pipe (equation (6.13)) satisfy the physical conditions. It also explains the discrepancy in Fig. 9 between the 1/7th power law and the experimental results near the surface of the plate.

REPLY TO THE DISCUSSION.

The paper was intentionally provocative. He had hoped that Professor Taylor would have responded to the provocation, but, unfortunately, he had to be at Aberystwyth.

Commenting on Dr. Richardson's suggestion that Burgers had over-corrected his hot wire readings, he said he believed that Hansen had secured much better agreement between experiments and Blasius's formula than Burgers had done.

With regard to Dr. Piercy's suggestion that the boundary layer theories ought to be applied to three dimensions, Professor Bairstow said he had deliberately chosen two dimensions as far as he could for illustration, in order not to make the mathematics any more difficult than it was. But it was quite true that most of the problems dealt with involved consideration of three-dimensional motion. Clark Millikan, of Pasadena, had worked in three dimensions for an airship with its axis along the wind and had calculated the boundary layer, both for laminar flow and on certain assumptions at its transition for turbulent flow; Miss Hilda Lyons had made experiments on an airship form and had compared those calculations with her experiments. She was one of those who appeared to feel some difficulty in accepting the one-seventh power law, and left her formula so that the one-eighth or one-ninth or any other might be used. But Professor Bairstow agreed with Dr. White that they should be thankful for what they had at the moment, even if they considered them only as steps to something better; nevertheless, he urged that there was reason why they should not be content with them. One of the objects of the paper was to stir up enthusiasm in such people as could work on these problems, so that they could secure greater accuracy in accounting for observations.

Dr. Lachmann asked that they should have experiments on real wings instead of experiments in the compressed air tunnel; Professor Bairstow said he did not distrust the experiments in the compressed air tunnel, for he thought they were perfectly sound. On the other hand, experiments such as Dr. Lachmann wished for were being made, but it would not be fair to say very much about them at the moment. They were being made by Professor Jones, at Cambridge, Mr. Haslam acting as pilot; Mr. Farren had designed instruments, and the cost of the experiments was being met from Sir John Siddeley's £10,000 fund.

Measurements of the drag of a smooth wing as well as of a fabric-covered wing had been made in flight, and in due course the results of those experiments would be available. Modifications of roughness would also be made on the same aeroplane.

Professor Bairstow supported Dr. Maccoll's suggestion that the problem of the boundary layer, when compressibility mattered, was due for attention. Whether or not the work could be done at the universities he did not know. Dr. Hilton, a student at Imperial College, had been carrying out experiments on compressibility in airscrews, measuring shock waves, etc., and one hoped that the National Physical Laboratory would shortly possess apparatus for dealing with compressibility effects on aerofoils, etc. The reason why it was difficult to get some of the apparatus into the Imperial College or other university department was that some of it made a great deal of noise. Further, considerable power was needed. At the N.P.L. the exhaust from the compressed air tunnel could be used to drive a 1ft. tunnel up to, say, 900ft. per second. The kind of apparatus required could not be bought or housed by a university.

Dealing with Mr. Falkner's question as to whether research should proceed in the direction of piling up a lot of information of a given kind or should be directed rather to fundamentals, he said he hoped that when there were available people who were capable of doing fundamental work they would be encouraged to do it and he appreciated work of the kind already done at the National Physical Laboratory. Mr. Fage, Dr. Townend and Mr. Simmons had all been working on turbulence from a rather more fundamental point of view than was dealt with in the paper; they had been measuring turbulence, and one important law had already come out of their work. Taking any one particular variable, say axial velocity, it seemed that the variations from the steady motion were quite casual and obeyed the normal error law. But when one considered the necessary connection between two velocities, one at right angles to the mean flow and another along it, there must be an instantaneous connection and the two must be correlated. He believed Dr. Townend had done some work on correlation by passing hot spots down a stream and measuring the ovals, which were seen after some little time; the inclination of those ovals, and their dimensions, gave some measure of the correlation coefficient. It seemed that if that kind of work could be carried to a definite conclusion it would constitute the best kind of help towards understanding turbulent motion and enabling them to make the next step forward in theory. Such work was eminently suitable for a university; Professor Bairstow's difficulty at the moment was, not that he was not anxious to do it or had not the money, but that he had not a student to do it.

Discussing the question as to what was the effect of a heated surface upon the boundary layer, he said he did not know that any very elaborate work had been done on the subject, but the effect was not expected to be very great; the general opinion at the moment was that, if one took for the viscosity the value corresponding with the temperature of the hot surface, and used that in the Reynolds numbers, etc., one would get pretty nearly the right answer. But it was not an elaborate theory worked out in the same way as most of the other theories.

Professor Bairstow agreed thoroughly with Mr. Fage that if one argued from one experiment to another of a similar nature, say, from one aerofoil form to another aerofoil form, one would probably attain very considerable accuracy in one's results. If one wished to examine a particular case one could do very much better by looking up the nearest experimental information and adopting that as the starting point.

As to the parabolic relation for flow in pipes, which he had attributed to Stanton, Professor Bairstow said that the particular work he was referring to was published in the Proceedings of the Royal Society, he believed in 1911. In that work, Stanton, before measuring the velocity distribution, had roughened his pipe very carefully in order to obtain a resistance coefficient which was

independent of speed; in other words, he had obtained a resistance proportionate to the square of the speed, and it was only in that sort of pipe that one obtained distribution independent of Reynolds number. The parabola was quoted in the particular paper referred to; the curve was drawn through the points, and it was a very good fit indeed up to about 0.9 of the radius.

The PRESIDENT: In proposing a vote of thanks to Professor Bairstow, he said that, having known him for many years, he had always regarded him as a mild, standard, inoffensive citizen; but when he talked for an hour and a quarter in a jargon which was entirely incomprehensible to the layman, the latter must regard him as a sort of superman endowed with a most extraordinary knowledge. But the lecture was essentially of the type which the Royal Aeronautical Society must have. To the ordinary layman it appeared that they must strive after a smooth skin; many people knew that before! However, the paper was not the first great contribution that Professor Bairstow had made to the knowledge of a very difficult technical subject; the Society welcomed him as he deserved to be welcomed, and hoped that soon he would be able to communicate even more information upon the difficult subject with which he had dealt, for it was becoming more and more interesting by virtue of the increased speed of the aeroplane.

(The vote of thanks was carried with enthusiasm, and the meeting closed.)

The 606th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS.

A meeting of the Society was held in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, on Monday, April 20th, 1936. In the chair: Mr. H. E. Wimperis (Director of Scientific Research, Air Ministry), Vice-President.

The CHAIRMAN: Dr. H. J. Gough, M.B.E., D.Sc., F.R.S., and Mr. W. A. Wood, M.Sc., were to present a paper on "Strength of Metals in the Light of Modern Physics." During the last 20 years Dr. Gough had served at the National Physical Laboratory and now occupied the position of Superintendent of the Engineering Division; Mr. Wood was serving in the Physics Department at the Laboratory. Thus, the paper was the result of the combination of the efforts of two men who were doing quite different kinds of work and were supplementing each other's knowledge in the light of their own particular lines of experience. The result of that combination was very attractive to the members of the Society.

Dr. GOUGH presented the paper.

STRENGTH OF METALS IN THE LIGHT OF MODERN PHYSICS

By H. J. GOUGH, M.B.E., D.Sc., F.R.S., and W. A. WOOD, M.Sc.

SUMMARY.

The strengths of the metals at present available to industry are of especial importance to the aeronautical engineer who is also in a position to appreciate the need for greatly improved materials, the absence of which often places restriction on much needed developments. Although the materials of the future may become available by the somewhat fortuitous development methods at present employed, it is undeniable that greatly accelerated developments would result if a correct understanding was obtained of the fundamental characteristics of the cohesion and fracture of metals, of which the former belongs to the field of the atomic physicist. The authors present an account of their recent work on the deformation and fracture of metals in which precise methods of X-ray diffraction have been employed in order to make a systematic study of the changes produced in the crystalline structure of metals subjected to static tensile, and static torsional stressing, also to three types of cyclic stressing or fatigue.

It has been found possible, for the first time, to show that failure under static and fatigue stressing is associated with changes in the crystalline structure which are identical. These changes are (1) a dislocation of the initially perfect grains into large components which vary in orientation from that of the internal grain by amounts up to about 2°, (2) the formation of "crystallites," approximately 10^{-4} to 10^{-5} cm. in size, whose orientation varies widely from that of the original grains, and (3) the presence of severe internal stresses in the crystallites. At fracture, whatever the type of applied stressing, the whole of the specimen behaves to the X-ray beam as a medium of crystallites showing marked lattice distortion and oriented completely at random. X-ray diffraction methods are shown to distinguish clearly between the effects of the application of safe and unsafe ranges of stress; the first method that has been successful in this respect.

In order to show the relationship between the new work described and

previous work dealing with the use of X-rays in studying the deformation characteristics of metals, a preliminary section of the paper deals with cold-rolling and drawing. A survey is also presented of the present position regarding strength and atomic structure, together with references to various theories regarding the imperfections of crystals as encountered in practice. An introductory section describes briefly the atomic structure of metals, as revealed by X-rays.

I. Introduction.

To engineers and designers in general faced with modern problems, the strengths and other properties of materials of construction form a subject of prime importance and direct interest; often, a much needed development is restricted only by limitations imposed by the available materials. The subject is of *especial* importance to the aeronautical engineer on whose skill and resource the bugbear of the power-weight factor imposes a strain of peculiar and increasing severity. In addition to the resistance of materials to the simpler straining actions, caused by static and impact stresses, he is much concerned with the resistance to cyclic stresses, or fatigue, particularly with regard to engine components. At the outset, it must be recognised that *one* primary problem only is involved, the fundamental problem of why materials fail, either by deformation or fracture; the actual stress condition involved—static, dynamic or cyclic—*must* be relatively unimportant. Until this problem is solved, it is necessary to make available the results of mechanical or other tests which express the " strength " of a material under a certain set of conditions—tensile strength, fatigue limit, notched-bar value, etc.—in a form which may be useful for design purposes, but such statements in themselves merely amount to a confession of the empirical state in which our present knowledge of materials exists, as such data are entirely useless in a search, on scientific lines, for new materials or even for marked improvements in existing materials.

How, then, are we to proceed in a systematic search for the new improved materials of the future, for of the development of such materials no one acquainted with the advances made within the present century even can have any real doubt? In the first place we must recognise that the properties of any metal or alloy—whether we regard it merely as a solid body, a chemical combination of various elements or as an aggregate of crystals—*must* depend ultimately on its inner crystalline structure as revealed by *physical* methods. It is common knowledge that metals consist primarily of an ordered arrangement of atomic nuclei and electrons; the properties of metals in the bulk form as used in industry *must* be related to the atomic forces and arrangement, although that relation may not be direct, neither must we hope that it will be simple. As part of the answer to our question, it appears obvious that we must use every endeavour to obtain a clear understanding of the physical conditions under which failure and fracture occur. This is the aspect of the problem which will probably occupy the major attention of the engineer; given such a knowledge, it *might* be possible to effect major improvements in materials. But it is illogical to assume that a correct interpretation can be made of the answer to the question of " Why metals break," unless it has also been made quite clear " Why metals hold together." Thus the problems of *cohesion* and *fracture* are really inseparable. The fundamental problem of the cohesion of matter—of which the cohesion of *metals* is one of the most complicated aspects—is one that must be left to the atomic physicist, who, using highly specialised technique and mathematical methods, is attacking the problem with such great energy and resource. Recent discoveries wtih regard to the nature of the atom have been so startling in their unexpectedness that this branch of physics has evidently not reached any state of finality and it appears extremely doubtful whether a quantitative theory of cohesion of the metallic state in general will be made available in the very near future. In view of this position, it is not unreasonable at the present time to

make some independent attempt on the problem of fracture employing the most precise physical means at our disposal, especially when it is remembered that the validity of any quantitative theory of cohesion must involve reasonable agreement with the characteristics of fracture as determined experimentally.

The chief object of the present paper is to present the results of some investigations, made by the present authors, into the characteristics of deformation and fracture of metals as revealed using X-ray methods of precision. The primary objects in view in carrying out the work[1] were (1) to determine the essential condition of the crystalline structure under which fracture occurred, (2) to examine whether fracture, whether due to static or cyclic stressing, did or did not represent the attainment of a definite common condition of the crystalline structure, and (3) to determine whether the " fatigue limit "—that invaluable property to engineers—did mark a dividing line between critical conditions of the structure such that the X-ray method of examination would distinguish clearly between the effects of cycles of an " unsafe " and a " safe " range of stress. Reviewing broadly the results obtained, it may be said all three objects have been attained with considerable success while much new light has been thrown on the finer aspects of the *deformation* of metals.

A word of apology should, perhaps, be offered in explanation of the preliminary sections of the paper. In the first place, the lessons derived from the observations made during the research necessarily depend upon the interpretation of the spectra obtained from the precision X-ray methods employed. It was considered that it might be helpful to recall some of the essential facts on which such interpretation is based and this has been done in the first preliminary section of the paper. Again, the observed changes occurring in the crystalline structure during deformation and at fracture suggest strongly that the metal used, in its original unstressed state, was not in the homogeneous condition attributed to the perfect theoretical crystal. There have previously been offered many suggestions—based on experiment or theory—that the metallic crystal, as encountered in practice, has some form of system of flaws or secondary structure superimposed on the primary crystalline structure as revealed by ordinary X-ray methods; a brief summary has, therefore, been given of the more important of these suggestions regarding imperfections of crystals which may be compared with the results of the present research. A short section is also devoted to relevant results obtained from the X-ray examination of metals deformed by cold-rolling and drawing.

We trust that this consideration of the work of other experimenters together with the results obtained in the authors' researches, will lead to the conclusion that, by using modern physical methods, a definite beginning has now been made in a correct understanding of the changes in structure which occur in the deformation and fracture of metals; a definite step towards the desired conception of the strength of metals. That precise physical methods offered the only useful weapons of attack on this essentially engineering problem will be evident, but it is certain that, once the fundamental principles of cohesion and fracture are really understood, directly useful applications to engineering construction must surely follow. For this reason, the authors have no hesitation in presenting the present paper to the Royal Aeronautical Society.

[1] In this work much attention has been given to the fatigue aspects for various definite reasons. In the first place, fatigue is recognised as one of the most urgent of the engineering problems of materials; secondly, it is *convenient* to use cyclic stressing as, with a uniform material, the essential characteristics—fatigue limit, endurance, etc.—can be repeated on successive specimens, subjected to fatigue stressing, with much greater reliability than with any other form of stressing; also, the *course* of failure can be most conveniently studied at various progressive stages of a test on any one specimen; also, under suitably chosen stress conditions, the changes in shape of the specimen can be reduced to a minimum. Nevertheless, the essential facts which emerge from the research are capable of much wider interpretation than as relating to fatigue.

II. Crystal Structure and X-Rays.

A growing understanding of the physical properties of materials has arisen largely as a result of our rapidly increasing knowledge of the atomic architecture of the solid state. In the majority of cases, Nature builds up a solid, molecule by molecule, according to a regular plan. The molecular units of organic substances, such as wool, hair or muscle, are usually large and unwieldy; often the regularity is incomplete, or, as in rubber, is evident only when the material is stretched and the molecular chains lie uncoiled, side by side. But in the inorganic world, to which most industrial materials belong, the unit molecule is small, and the resulting structure follows a simple, precise pattern; the material is then said to be crystalline. One of the main achievements of modern physics has been the determination and measurement of the pattern for innumerable substances.

It may be useful now to recall the main features of the crystalline state and then to describe how, with the help of X-rays, the atomic arrangement is revealed. In doing so, it is convenient to start from the conception of a simple pattern of points in space which is termed a space-lattice. Suppose we divide up space into a system of cells by means of three intersecting families of planes, the members of each family being parallel and equi-spaced. Suppose that a point is placed at the corner of each cell. These points then form a space-lattice; this is illustrated in Fig. 1. It is evident that such an array of points can be

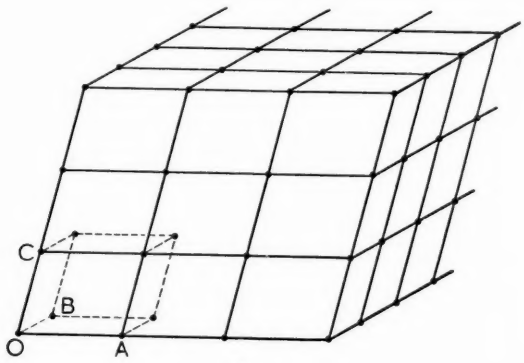

Fig. 1.
The Space Lattice.
To save confusion, one unit cell only is indicated (OA, OB, OC). The three families of parallel equi-space planes forming the lattice are:—
(1) *The set parallel to plane OAB.*
(2) ,, ,, *OAC.*
(3) ,, ,, *OBC.*

traversed by a number of families of parallel planes, and that any three families will enclose a system of cells. It is customary, however, to consider only the cell which has the simplest geometrical shape. This cell is the "unit cell."

If now we replace every point by a similar group of atoms, each group and its components being identically arranged, we have a crystal. The simplicity of this arrangement in inorganic materials, such as metals, is emphasised by the fact that normally the number of atoms in the unit group is quite small, being of the order of two, three, or four. The structure of iron, shown in Fig. 2, may be quoted as an illustration which is of particular interest since the specimens used by the authors, in the work referred to later, were of mild steel. Here

the points of the space-lattice form the corners of cubes with a side of 2.86 A ($1A = 10^{-8}$ cm.). With each point is associated two atoms, one at the corner and one at the centre of the cube. This gives a unit cell with an atom at each corner and one in the middle of the cube. In the polycrystalline aggregate, which is the metal in its normal form, this cubic distribution of atoms extends throughout each grain in a similar manner. The structure is broken irregularly at the grain boundary. In neighbouring grains, the inclinations of the axes of the cubes are in general different, one grain being joined up to the next in a manner which is still not definitely known.

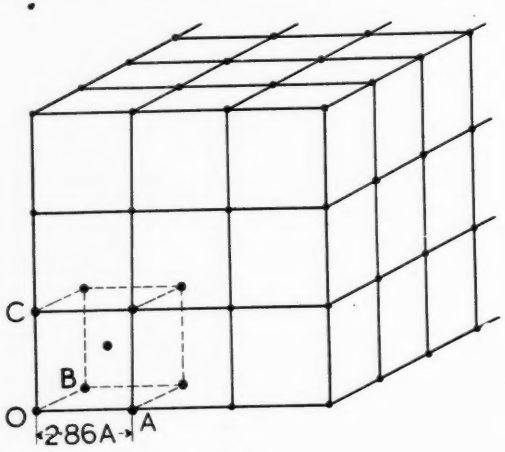

FIG. 2.

Atomic Structure of Iron.

One cubic unit cell only is indicated, defined by $OA = OB = OC = 2.86\,A$. The corners and the centres of each cube are occupied by iron atoms. Two atoms may be considered to belong specifically to each cube; the atom at the corner corresponding to O, and the atom at the centre of the cube. This structure continues until stopped irregularly at the boundary of the grain.

Turning now to the interaction of a crystalline grain and a beam of X-rays, consider a narrow beam of rays of a particular wave-length which falls on a definite family of planes at a angle of incidence θ, as shown in Fig. 3. The first plane scatters part of the beam and, as in the reflection of light by a mirror, the scattered beam has a maximum intensity when the reflection angle is equal to the angle of incidence. The process differs, however, from the optical analogue because of the power of the X-rays to penetrate matter. As a result of the penetration partial reflections occur also at the second, third and other planes, again at the angle θ. The effect of the subsidiary reflections is to impose an extra condition. By this condition, reflection occurs when, and only when, the angle of reflection θ satisfies the condition $2\,d \sin\theta = n\lambda$ ($n = 1, 2, 3 \ldots$) where d is the spacing of the planes and λ the wave-length of the X-rays. At this angle then, considering the first order reflection only ($n = 1$), the family of planes behaves to the X-ray beam as a mirror to a beam of light, and would reflect on to a suitably placed photographic film an image of a point source of X-rays as a spot.

It is convenient to consider the practical case arising when the size of the grains is so small that the volume penetrated by the X-ray beam contains more than one grain. Consider the same set of planes in each grain. In some grains the planes will be correctly inclined to the beam and a reflection will occur. It is evident from Fig. 3, that the reflected ray makes and can only make an angle 2θ with the incident beam. Any other grain that happens to be in a position to reflect therefore can only produce a reflection also inclined to the incident beam at the angle 2θ. All such reflected beams therefore will lie on a cone which has the incident beam as axis and the angle 2θ as the angle. This cone will cut a photographic film in a ring or curve according to the position of the film. This is termed the (h, k, l) diffraction ring where (h, k, l) are indices defining the particular family of planes considered. Each set of planes will produce its own ring.

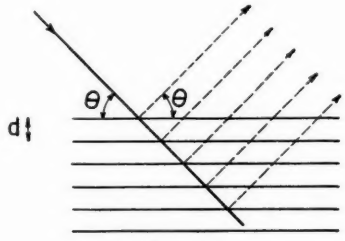

FIG. 3.

Reflection of X-rays by a family of atomic planes. The reflections from successive planes co-operate only when the path-differences are equal to an integral number of wave-lengths; i.e., when $n\lambda = 2d \sin \theta$.

The number of reflection spots on a diffraction ring is obviously proportional to the number of grains in the volume penetrated by the incident X-ray beam. Under customary experimental conditions, the spots would be separated if the size of the grains were greater than 10^{-2} cm. If the size of the grains were reduced to the order of 10^{-4} cm., thus increasing the number of grains in the illuminated volume, the spots would be sufficient in number to coalesce and form a continuous line. This technique has been used by the authors in following the breakdown of the grains of a metal under static and cyclic stresses.

The sharpness of the reflection from a grain depends, other things being equal, on its degree of perfection. This point is illustrated in Fig. 4. In practice an incident X-ray beam is *always* somewhat divergent. A perfect grain in the reflecting position will automatically pick out from the divergent beam that portion only which is incident at the definite angle θ. If the grain is imperfect, in the sense that different parts are dislocated and slightly inclined to each other, then each part will select from the incident beam a portion making with its surface the angle θ, and produce a reflection. The total reflected beam is therefore also divergent and the reflection spot on the photographic film will be elongated by an amount proportional to the angular tilt of the components of the imperfect grain. This technique also was used by the authors in studying the first stage of breakdown of a perfect grain into a mosaic.

The breadth of a diffraction ring depends also on the size of the reflecting grains. We have mentioned that the penetration of an incident beam into a grain, producing partial reflections from successive members of a family of planes, limits the law of reflection and results in reflection at one angle only. It is evident that the angular limits between which the reflection will be concen-

trated will depend on the number of the planes in the family considered, and this, in turn, on the size of the grain. In practice, broadening of the ring on this account begins only when the size of the grain is less than about 10^{-5} cm., but thereafter increases rapidly. *These considerations lead to methods of estimating changes in grain size in a region beyond the power of the microscope.*

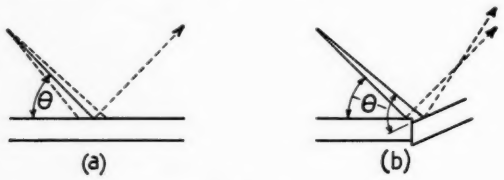

FIG. 4.

Reflection by a Perfect and by an Imperfect Crystal.

(*a*) *The perfect crystal selects from a divergent beam the ray inclined at the reflecting angle θ and gives a sharp reflection.*

(*b*) *The broken crystal possesses facets which may be inclined at the angle θ to divergent portions of the beam; the reflection is not sharp (the effect is exaggerated for illustration).*

Without going into further detail, it will be apparent that the application of X-ray analysis leads to the determination of atomic structure and to a method of following changes in the crystalline grains composing a material under various conditions of experiment. In addition, it will also be seen that knowledge of a structure provides a starting point for the theoretical physicist to attack the problem of the binding forces between the atoms, and to proceed to a study of the question of cohesion on which the strength of materials ultimately depends. In the next section we summarise the present position of researches along these lines.

III. STRENGTH AND ATOMIC STRUCTURE—SURVEY OF PRESENT POSITION.

(*a*) *Structure-Sensitive Properties.*

Given the positions of the atoms and the forces between them, it should be possible to calculate the strength of a solid. The atomic positions in numerous crystalline materials are now known as a result of X-ray analysis. The interatomic forces, though still not understood clearly in the majority of cases, are known for the simple ionic[2] type of structure, like rocksalt, where they are mainly electrostatic. For this type of structure, therefore, it has been possible to calculate the theoretical values of a number of physical properties. The first calculations were made by Born and Landé in 1918. It has since become evident from the applications of Born's theory, that the theoretical physical properties are of two classes; in the first, they are in good agreement with observed values; in the second, they are at variance, although the same assumptions are used. Properties of this latter type have been termed by Smekal[3] " structure-sensitive "; they include electrical and thermal conductivities, diffusion constants, dielectric strengths, hardness and magnetic properties. The strength of a crystal also

[2] The structure consists merely of positively and negatively charged atoms (Sodium and Chloride) arranged alternately; the atoms are held together by forces of mutual attraction and repulsion due to the charges as distinct from " homo-polar " binding, where the atoms are held together by mutually-shared electrons.

[3] A. Smekal, Handbuch der Physik, 2nd Edition (Berlin, 1933).

(or the force required to separate it into two parts across a crystal plane), is a structure-sensitive property. Thus, Zwicky[4] calculated the strength of rocksalt to be 200 kgm./mm.^{2}; the observed strengths are normally of the order of 0.2 kgm./mm.^{2}.

The observation that in the same crystal some properties may be calculated and others not as directed attention to differences between the *ideal* and the *real* or actual crystal. Ways in which the real crystal deviates in structure from the ideal have been the subject of a great number of researches. The relevance of the deviations found to the question at issue has, however, often been overlooked. Since the properties of a given material tend to reproduce at approximately similar values, they have been associated by certain workers with deviations in structure which follow some sort of system. The main proposed structures are briefly referred to below.

(*b*) *Secondary Structures.*

(i) *Superstructures (Zwicky)*[5].—Zwicky has supposed that every nth plane in a crystal is abnormal so that a large-scale lattice or superstructure is superposed on the ideal atomic lattice. In his later papers, the anomalous planes are caused by an excess of atoms. Zwicky has sought to give a theoretical basis to his suggestion by calculations which set out to prove that the superstructure confers an increase of stability on the lattice; the validity of these, as Pauling, Orowan,[6] and others have shown, is questionable. Practical evidence for superstructures is usually of the type advanced by Goetz,[7] who photographed the surface markings on the basal cleavage plane of bismuth and claimed that they formed regular triangles of side 1.4×10^{-4} cm. Similarly, Dean and Koster[8] found marked regularity in the " tear " lines of bismuth. The etching pits in iron studied by Belaiew[9] have been taken to indicate a regular structure of side 0.25×10^{-4} cm. A similar interpretation has been placed on the results of Straumanis[10] who found that zinc and cadmium crystals, grown by sublimation in vacuo, form a stepped arrangement of plates about 0.8×10^{-4} cm. thick. We consider it unlikely, however, that these phenomena, which are not easily resolved by the microscope, possess the absolute regularity required by Zwicky's theory.

(ii) *Lineages (Buerger)*[11] *and Block-Structures (Smekal)*[3].—Buerger considers that all real crystals are built up of " lineages " or branches which radiate from the initial nuclei of growth, sub-dividing into lesser lineages until the whole volume of the crystal is solid. The main evidence again is based on observations of defects by the microscope. The lineages do not necessarily divide the crystal into separate compartments. In this respect the theory differs from that of Smekal; according to the latter, a crystal is an aggregate of small blocks (10^{-5} to 10^{-6} cm.) which arise inevitably from variations in orientation, or foreign atoms; these he terms primary flaws as distinct from secondary flaws which may follow upon subsequent heat or mechanical treatment and which easily attain visible dimensions.

The objection one has to these theories is that they are not entirely relevant or necessary to the explanation of the weakness of materials. Thus it is not

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[4] F. Zwicky, Z. fur Phys. **25**, p. 223, 1924.
[5] F. Zwicky, Proc. Nat. Ac. Sci., U.S.A. (a) **15**, p. 253, 1929.
(b) **15**, p. 816, 1929.
(c) **17**, p. 524, 1931.
Phys. Rev. (a) **40**, p. 63, 1932.
(b) **43**, p. 765, 1933.
[6] E. Orowan, Z. fur Phys., **89**, p. 774, 1934.
[7] A. Goetz, Proc. Nat. Ac. Sci., **16**, p. 99, 1930.
[8] R. S. Dean and J. Koster, " Mineral Physics," U.S. Bur. Mines, p. 17, 1933.
[9] Belaiew, Proc. Roy. Soc. A, **108**, p. 295, 1925.
[10] M. Straumanis, Z. fur Phys. Chem. B, **13**, p. 316, 1931, and **19**, p. 63, 1932.
Z. fur Krist., **75**, p. 430, 1930.
[11] M. J. Buerger, Z. fur Krist., **89**, p. 195, 1934.

difficult to show how the strength of a body can be markedly influenced by superficial flaws, and how the effect of such flaws can be varied in a way which need not involve the secondary structures in the volume of the solid. Also, the theories do not touch the case of solids, such as glasses, bakelite and other plastics, which are not crystalline. On the other hand, these researches have emphasised the mosaic nature of crystals which often appear optically perfect. The most direct evidence of such a mosaic is given, however, by X-rays.[12] Darwin, Bragg and James concluded from their measurements of the extended angular range over which rocksalt reflects X-rays and from the intensity of reflections, which depends on the degree of degeneration from the perfect to the mosaic form, that the elements of the mosaic are approximately 0.5×10^{-4} cm. in average size.

(c) Theory of Flaws.

Joffé[13] and his school, in a series of interesting experiments on ionic crystals, have demonstrated the weakening effect of minute cracks and flaws on the lines of Griffith's[14] original experiments which showed, for instance, that the strength of quartz and glass rods, protected from superficial flaws, could be increased tenfold. Joffé found that the strength of rocksalt in hot water, which would tend to heal the flaws, might reach 10 kg./mm.^{2}. Higher values up to 20 kgm./mm.^{2} are attained, as in work by Piatti,[15] when the rocksalt is very carefully stretched in salt solution at room temperature. Similarly, Orowan[16] has pointed out that the strength of mica, clamped in a way which rendered inoperative the effect of the inevitable cracks at the edges, exhibited an increase from 30 kgm./mm.^{2} to the remarkably high value of 300 kgm./mm.^{2}. Such experiments lead to the theory that every solid is characterised by an inherent system of flaws which are distributed throughout the body without reference to superstructures, block or lineage formations, and that failure occurs at comparatively low stresses because a concentration of stress at a flaw may rise to the theoretical value of the strength, although the mean stress may be many times less. This theory in its original form has been criticised because in plastic crystals the faults would need to be of the order of 0.5 mm., which is too large; this difficulty is removed, as shown by Orowan, if consideration is taken of the action of neighbouring glide planes. This modified theory appears the most consistent with present knowledge. It should be remembered, however, that plastic crystalline aggregates, such as rocksalt or metals, form a special case because they involve the processes of gliding and twinning.

(d) Mechanism of Slip in Crystalline Solids.

The failure of plastic crystalline solids is bound up with the effect on the structure of progressive glide movements and twinning. The position with regard to the *mechanism* of gliding has been largely cleared by the introduction of the conception of "dislocations" (G. I. Taylor)[17] or "Versetzungen" (M. Polanyi).[18, 19] These conceptions offer a plausible explanation of the fact that slip takes place upon the application of shearing stresses much less than the values required theoretically to move one plane of atoms bodily over a neighbouring plane, expressed in diagrammatical form in Figs. 5 and 6.

In order that a slip motion may occur, an atom must jump into the position occupied by its neighbour. In an ideal lattice of stationary atoms, the required force would be extremely large. In practice, therefore, the potential barrier

[12] R. W. James, Z. fur Krist., **89**, p. 295, 1934.
[13] A. Joffé, "Physics of Crystals," McGraw Hill (1928).
[14] A. Griffith, Phil. Trans. Roy. Soc. A, **221**, p. 180, 1921.
[15] L. Piatti, Z. fur Phys., **77**, p. 401, 1932.
[16] E. Orowan, Z. fur Phys., **82**, p. 239, 1933.
[17] G. I. Taylor, Proc. Roy. Soc., **145**, p. 362, 1934.
[18] M. Polanyi, Z. fur Phys., **89**, p. 660, 1934.
[19] E. Orowan, Z. fur Phys., **89**, p. 314, 1934.

round an atom about to jump must temporarily be lowered and the neighbouring position must be available. It may be shown that this would happen if, for instance, we had a structural condition in which $(n+1)$ atoms on one side of a potential glide plane are facing n atoms on the other side (see Fig. 6 (*a*)), where normally n atoms should face n atoms. Such a condition might conceivably arise during the thermal fluctuations of the atoms; also it would arise when a

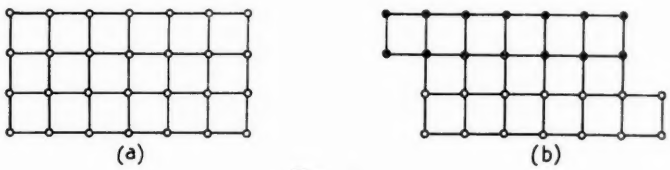

FIG. 5.

Illustrating Deformation by Glide of Atomic Lattice.
(a) Before glide. (b) After glide.
● *indicates atoms which have undergone a "glide-jump."*
○ *indicates atoms unaffected by the glide.*

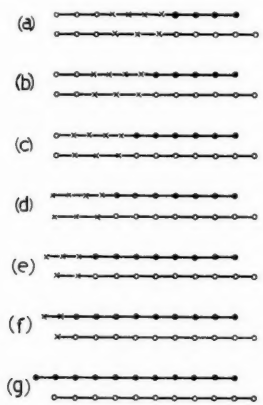

FIG. 6.

Illustrating successive stages in the passage of a dislocation finally resulting in the glide of one plane of atoms over another.
● *indicates atoms which have made a "glide-jump."*
○ *indicates atoms still unaffected by the glide.*
X *indicates the "zone of dislocation," i.e., abnormally placed atoms situated between the atoms which have undergone a glide and those still unaffected.*
It is seen that the initial partial glide causes four atoms in the upper plane to face three atoms in the lower plane in the zone of dislocation. (These numbers are used arbitrarily for illustration.)

local slip had occurred (owing to a stress-concentration effect at a local inhomogeneity or flaw) in the zone separating the part of the crystal which had slipped from that which had not. The abnormal configuration represents a zone of dislocation as indicated in Fig. 6.

The dislocation is then the means by which a slip movement is transmitted. Thus one might consider that at the boundaries of the zone, the atoms above

and below the potential slip plane are vibrating in phase. At the centre of the zone the vibrations would be out of phase because an extra atom on one plane has to be allowed for; the equilibrium at the centre would therefore be on the border of instability and a slight stress only would produce a movement tending to bring the atoms opposite each other in the normal arrangement; the most unstable atom having been moved, the next atom becomes the centre of the dislocation, and that in turn moves until the dislocation has passed along the glide plane, leaving a translation of one part of the crystal relative to the next by one atomic spacing.

The reason for the increase in hardness, or resistance to further shear, which accompanies a slip movement is still not perfectly clear. Taylor,[17] however, has estimated the stresses arising when the dislocations in a given volume are sufficiently numerous to interfere with each other; he finds that an applied stress is required to set the dislocations in motion which varies inversely as the distance between them. The crystal has therefore a finite strength depending on the number of dislocations per unit volume. Taylor therefore explains the increase in hardness on the assumption that plastic deformation results in the automatic creation of *more* dislocations. For a complete explanation, however, more information is required regarding the origin, length of path and mutual influence of the zones of dislocation; also of the changes in crystalline structure which a slip movement leaves in its wake. Definite information on the latter point is given by the effect of the deformed structure on X-ray reflections as shown by the work of the present authors; this will be discussed later for the cases of deformation by cold-working under static and cyclic stresses.

IV. Relevant Results from the X-Ray Examination of Metals Deformed by Cold Rolling and Drawing.

In recent years the changes produced in the crystalline structure of a metal during progressive cold-working have been related to the degree of deformation and to changes in physical properties. It has been found that the changes occur in a definite sequence.[20] The main points of significance in connection with the present subject, are summarised below.

(*a*) *Breakdown of the Grains.*

The immediate effect of plastic deformation in general is to break down the grains into smaller units within the original grain boundaries. This process often affects the X-ray diffraction photographs markedly before any appreciable visual change appears in the grain boundaries as shown by the metallurgical microscope. The major changes, however, are complete after the first few per cent. reduction in thickness of the specimen.[21]

There is a lower limit to the size of the smaller units, or fragments, which can be produced by progressive cold-deformation. The limit is normally of the order of 10^{-4} to 10^{-5} cm. and is the same for a given metal in a given phase or state of purity.[22] This is proved by application of the fact that the breadth of a line in the X-ray diffraction spectrum depends on the size of the crystallites. Thus, taking a particular set of experiments on nickel[23] for illustration, theoretically we should have for the (311) line:—

Size of Crystallites.	Change in Line Breadth.	Remarks.
10^{-4} cm.	+0.024 mm.	Negligible.
10^{-5} cm.	0.24 mm.	Observable.
10^{-6} cm.	2.40 mm.	Large change.
10^{-7} cm.	24.0 mm.	Tremendous change.

[20] W. A. Wood, Phil. Mag., XIV, p. 656, 1932.
[21] W. A. Wood, Phil. Mag., XV, p. 553, 1933.
[22] W. A. Wood, Trans. Far. Soc., XXXI, p. 1248, 1935.
[23] W. A. Wood, Phil. Mag., XX, p. 964, 1935.

Actually it was found on continued deformation that the line-breadth, if it changed at all, did *not* increase indefinitely but approached a limiting value corresponding to a size of 10^{-4} to 10^{-5} cm. for the crystal fragments. *The above figures are given to show that any further decrease in size of the crystallites would affect the diffraction line so markedly that the proof of the existence of the lower limit is based on a very sensitive method of observation.*

The limiting value depends on the metal. The existence of the limit has led to the suggestion that the rate of breakdown, which is so rapid in the early stages, must be balanced on continued cold-working by a process of recrystallisation by which the broken crystallites are re-absorbed into the larger grains.[20] The only alternative is that the strength of the final crystallites is greater than the forces which can be applied in such processes as cold-rolling and drawing.

It is significant that when, in a given metal, the size of the crystallites is reduced by some other process to values less than the above-mentioned limit, then the *hardness* of the metal is *increased*. If the reduction is large, then the change in hardness may be extremely marked.[22] Examples are provided by the electro-deposition of chromium and nickel,[23] where the factor interfering with normal growth is probably the co-deposited gas, oxide and hydroxide. A further example is given by the nitriding of steel where, as the hardness is raised from a few hundred to over a thousand (D.P.H. values), the line-breadths are increased tremendously.[24]

(b) Lattice-Distortion and Selective Orientation.

Part of the broadening of the X-ray spectral lines from a cold-worked metal may be due to the *distortion* of the atomic lattice, involving local irregularities in lattice parameters. The effect of such local centres of distortion may be considered similar to that of fragmentation because two neighbouring parts separated by a zone of distortion would behave as separate units to an incident X-ray beam; thus separate contributions to the reflected beam would be thrown out of phase in an irregular manner, as if they came from separate fragments. The observed existence of the limit to the line-broadening, whatever its cause, places also a limit upon the maximum degree of distortion due to deformation.

The phenomenon of " preferred orientation " or " fibre structure " in which the crystal fragments all tend to align themselves in a definite crystallographic direction, begins to appear after the main changes involving fragmentation and lattice distortion have taken place. Much work has been done on the relation of this preferred orientation to the axis of the specimens used, in various methods of cold-working, and some attempts have been made to associate the *degree* of preferred orientation with the changes in physical properties produced by the deformation. But it has been shown that such an association, if indeed it exists, must be fortuitous, because the orientation grows and becomes marked only in the later stages of deformation, long after the main modifications in the properties have occurred.[20, 25] *This indicates that the critical processes are to be found in the fragmentation and distortion.*

(c) Associated Changes in Physical Properties.

A series of experiments in recent years has confirmed the result that changes in such properties as *hardness* are associated with such fragmentation and distortion. Most work up to the present has been done on these aspects because it is possible to obtain quantitative measurements of the changes in breadth of an X-ray spectral line under conditions of suitably high dispersion. We may quote, in addition to the above-mentioned cases of electro-deposited chromium and nickel and of nitrided steels, work on cold-rolled metals,[26] on 18/8 nickel-

[24] W. A. Wood, Phil. Mag., XVI, p. 719, 1933.
[25] W. A. Wood, Proc. Phys. Soc., 44, p. 67, 1932.
[26] W. A. Wood, Phil. Mag., XIX, p. 219, 1935.

chromium steel and manganese steels deformed by stretching, also, on heat-treated tungsten steels.[27] Also, experiments on tungsten magnet steels and silicon transformer steels show that an increase in coercive force and hysteresis losses, respectively, are brought about by the above changes in crystalline formation; electrical resistivities have been shown to be modified by the same changes in the case, for example, constantan and mica. Illustrative photographs are reproduced in Fig. 7.

V. Researches into Fatigue Phenomena which Led to the Present Investigation.

The research to be described represents a new method of attack, employing precision X-ray technique, upon the familiar but elusive problem of the failure of metals under repeated cycles of stress. The employment of this method, however, arose directly from the results of previous work made with the same main object in view; a brief prefatory statement of these earlier results may be useful, therefore, in indicating the type of information which it was hoped would result from the present experiments.

The failure of metals under cyclic stresses by the essential process of the formation and progressive spread of fine cracks—by long and common usage associated with the somewhat misleading term "fatigue"—has received extensive study at the National Physical Laboratory, where a lengthy series of related researches[28] have been carried out, principally on behalf of the Department of Scientific and Industrial Research. These investigations fall naturally into three main groups:—

In the first group are included studies of the stress-strain conditions existing in the cyclic state,[29] the effect of stress concentrations set up by sudden changes in shape,[30] the influence of impressed test conditions on the fatigue range,[31] atmospheric action as a factor in fatigue,[32] failure by fatigue in a corrosive environment,[33] failure under combined fatigue stresses,[34] etc. Much interesting and useful information was thereby derived concerning the observed characteristics of fatigue phenomena, together with numerical data relating to the stress conditions under which failure occurred or could be avoided. But no appreciable advance was made towards the solution of the fundamental problem of fatigue and, in fact, it is now realised that none can reasonably be expected to result from this type of investigation. After consideration, it was concluded that a deeper insight into the mechanism of failure might be obtained if the applied cyclic stresses were studied in relation to the resulting changes in microstructure; this led to the second group of investigations.

In this second group, polished specimens of various ductile metals, in the form of crystalline aggregates, were subjected to numerous ranges of stress of several types and careful observations made, using a metallurgical microscope, of the resulting changes in the appearance of the surfaces. It was established

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[27] W. A. Wood, Phil. Mag., XIII, p. 355, 1932.

[28] For critical reviews of this work and that of other investigators in the same subject, see:—
Gough (a) "Fatigue of Metals." E. Benn; (b) Trans. Faraday Soc., November, 1927; (c) Cantor Lectures, J. Roy. Soc. Arts, February, 1928; (d) Autumn Lecture, J. Inst. Met., Vol. 49, No. 2, 1932; (e) Proc. I.A.T.M., Zürich Congress, 1931; (f) 8th Edgar Marburg Lecture, Proc. A.S.T.M., Vol. 33, Part 2, 1933.

[29] Gough, "Engineering," September 8th, 1922.

[30] Southwell and Gough, Phil. Mag., Vol. I, January, 1926.
Gough, Repts. and Mem. Aero. Res. Committee, No. 743, 1921, and No. 843.

[31] Gough and Tapsell, Repts. and Mem. Aero. Res. Committee, No. 1012, 1926.

[32] Gough and Sopwith, (a) Jour. Inst. Metals, Vol. XLIX, No. 2, 1932.
(b) Jour. Inst. Metals, Vol. LVI, No. 2, 1935.

[33] Gough and Sopwith, Jour. Iron and Steel Inst., No. 1, 1933.

[34] Gough and Pollard, Proc. Inst. Mech. Engrs., November, 1935.

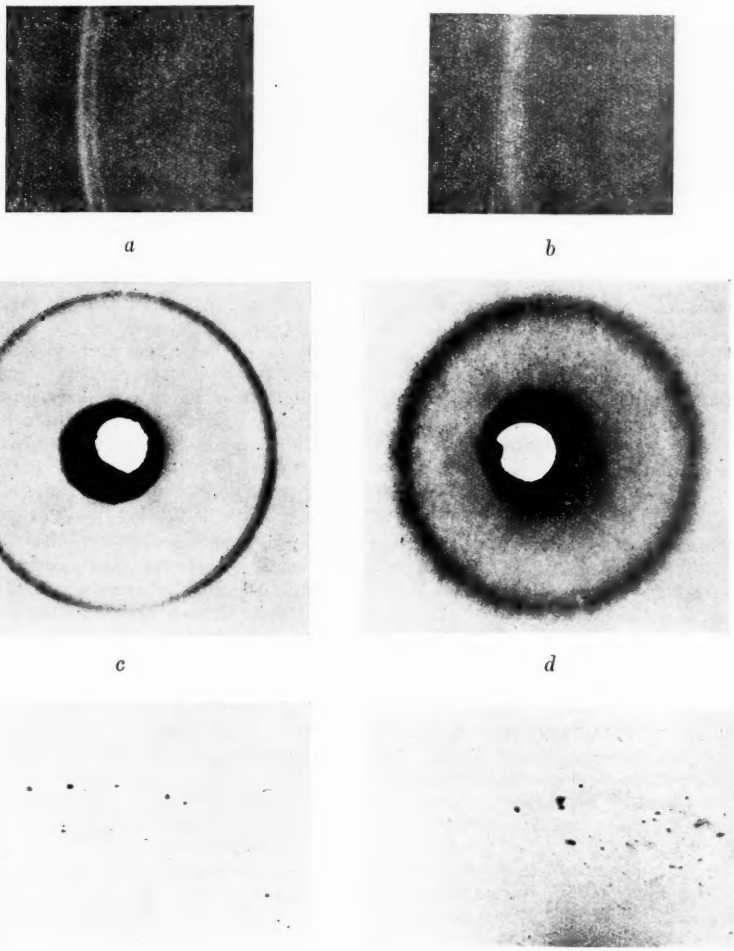


FIG. 7.

a, b, give arcs of X-ray diffraction rings, (a) from a tungsten magnet steel in soft condition, and (b) from same steel in hard, good magnetic condition. Note diffusion of lines in (b).

c, d, give diffraction rings, (c) from partially normalised chromium in soft condition, and (d) from chromium electro-deposited in very hard state. Note diffusion of ring in (d).

e, f, give diffraction spots from individual grains, in (e) good transformer steel, and in (f) same steel in bad condition with increased hysteresis loss. Contrast sharpness of spots in (e) with diffused type in (f).

For causes of diffusion, see text.

quite clearly[35] that, in every metal investigated, slip bands were formed alike by ranges of cyclic stress which were *insufficient* to cause fatigue fracture, and ranges which *exceeded* the limiting safe range; in the former case, the production of slip bands ceased at some stage, without further change in the appearance of the microstructure, while, in the latter case, cracks were initiated in regions of heavy slip. Thus, the important advance resulting from these investigations, in comparison with the results of previous workers[36, 37] who had also studied the fatigue of metals in relation to the resulting changes in microstructure, lay principally in the recognition and establishment of the fact that metals can be cold-worked under cyclic stresses, without fracturing, in apparently exactly the same manner as under static stresses. The observations led to the tentative suggestion that a certain limiting amount of strain-hardening, due to cyclic cold working, marked the dividing line beyond which crack formation commenced in local areas. The results also suggested that the critical conditions leading to the initiation of the fatigue crack were intimately related to the crystalline structure and probably were sub-microscopic in nature. To explore this aspect experimentally, attention was then diverted to the behaviour of large single crystals subjected to static and cyclic stresses, as applied stress conditions cannot be precisely related to the crystal structure in any crystalline aggregate of normal grain size; studies in this field formed the third group of researches which were undertaken.

In the group of researches dealing with the characteristics of single metallic crystals, also of specimens containing several large crystals, the crystallograph orientation with regard to the applied stressing system was determined by X-ray analysis, while changes of microstructure were observed using a metallurgical microscope; thus the observed characteristics of deformation and cracking were simultaneously correlated to the imposed stress system and to the crystalline structure. Extensive investigations have been made using crystals of aluminium,[38 39 40] iron,[41] zinc,[42] antimony,[43] bismuth,[44] and silver.[45] These have established that the general mechanism of deformation of ductile metallic single crystals under such diverse stress conditions as impact, static indentation and cyclic stresses of all types was intimately related to the crystal structure, occurring along certain crystallographic directions in certain crystallographic planes, being controlled by the simple criterion of maximum resolved shear stress (the same law as that established, by Taylor and Elam,[46] for the deformation of single metallic crystals under static tensile and compressive forces). Plastic deformation by slip occurred under safe and unsafe ranges of cyclic stresses alike; strain-hardening resulted to a degree proportionate to the amount of slip, and its effects were not specially oriented with regard to the slip plane but appeared to be effective throughout the immediate neighbourhood. In every crystal which failed, the fatigue cracks formed in a region which, previously, has been plastically deformed by slip; fatigue cracking of ductile metals thus

[35] Gough and Hanson, Proc. Roy. Soc. A, Vol. 104, 1923.
[36] Ewing and Humfrey, Phil. Trans. A, Vol. 200, 1903.
[37] Stanton and Bairstow, Proc. Inst. Civil Engrs., Vol. 166, 1906.
[38] Gough, Hanson and Wright, (a) Phil. Trans. Roy. Soc. A, Vol. 226, 1924; (b) Repts. and Mem., Aero. Res. Committee, No. 1022, 1925, No. 1024, 1926, No. 1025, 1926; (c) Jour. Inst. Metals, Vol. 36, No. 2, 1926. Gough, Cox and Sopwith, Vol. 54, No. 1, 1934.
[39] Gough and Sopwith, (a) Proc. Roy. Soc. A, Vol. 135, 1932; (b) Jour. Inst. Metals, Vol. 52, No. 2, 1933.
[40] Gough and Forrest, Repts. and Mem., Aero. Res. Committee, No. 1476, 1932.
[41] Gough, Proc. Roy. Soc. A, Vol. 118, 1928.
[42] Gough and Cox, (a) Proc. Roy. Soc. A, Vol. 123, 1929; (b) Proc. Roy. Soc. A, Vol. 127, 1930.
[43] Gough and Cox, Proc. Roy. Soc. A, Vol. 127, 1930.
[44] Gough and Cox, Jour. Inst. Metals, Vol. 48, No. 1, 1932.
[45] Gough and Cox, Jour. Inst. Metals, Vol. 45, No. 1, 1931.
[46] Taylor and Elam, Proc. Roy. Soc. A, Vol. 102, 1923, and subsequent papers.

appears to be associated with deformed metal, but, obviously, is not a *necessary* result of slip which, as stated above, can be produced under a range of stress which does not lead to eventual fracture. Neither is it essential that slipping must be in actual operation while the fatigue crack is passing from the sub-microscopic to the visible stage. For in one fatigue experiment made on a crystal which endured 9,270,000 stress cycles before fracture, no visible slip was being produced at the end of some number of cycles less than 7,000,000, and the fatigue crack finally appeared in a region which was entirely free from slip bands; this region had, however, been heavily deformed plastically during the earlier stages of the experiment.

The above summarised reference to previous work may be sufficient to show that, as the methods adopted progressed from mechanical, through mechanical plus optical, to mechanical plus optical plus X-ray, an increasingly satisfactory and comprehensive insight into fatigue phenomena was obtained. Failure of ductile metals under cyclic stressing undoubtedly has much in common with that due to static straining; probably the same essential process is involved although the conditions are so different that the nominal values of the operative stresses, also the appearance of the fractures, are substantially different; in relation to the metallic crystalline structure itself, imperfect as it is suspected to be, the state of *local strain* is almost certain to be the criterion governing failure, and no information whatever regarding the magnitude of these strains can be hoped for from a mere consideration of the external loading forces applied to the metal specimen (although, of course, empirical relations useful in engineering design will, no doubt, always be expressed in this form).

If the principal conclusions drawn from the previous work are reasonable, namely, that the essential conditions which control the formation of the fatigue crack in its earliest stages are sub-microscopic and intimately related with the crystalline structure itself, then it appears that, if the fundamental problem is to be pursued, future work must involve the more extensive use of those physical methods which are suited to exhibit the state of the crystalline structure at this critical stage.

Now, in the previous studies of the fatigue characteristics of single crystals, no difficulty was experienced in making X-ray analyses of the specimens in their most advanced stages of strain, but a certain deterioration in the sharpness of the spots was recorded[47], together with an increase in the range of setting angles over which reflections from a particular plane were obtained. These and other considerations indicated that the crystallographic planes became distorted in such a manner that, while their *average* curvature was inappreciable over a portion whose dimensions were of the same order as that of the X-ray beam itself, yet severe local curvatures existed. It was suggested that large local strains—also, possibly, actual lattice discontinuities—must occur in such distorted planes which, under the application of a sufficiently great range of external stress or strain, would lead to the formation of a progressive crack; under a lower magnitude of cyclic straining, the condition might be stable.

Some experiments made by Taylor and Gough[48] furnished some quantitative data of the condition of the slip planes of aluminium single crystals after deformation caused by static tensile stresses, also by cycles of direct stresses of moderately high frequency. Specimens plastically deformed under each of these conditions were sectioned parallel to the operative slip planes and quantitative measurements made of the intensity of the X-ray reflections from these slip planes. These intensities were measured, at different angles of setting, when the specimen was rotated (*a*) about the slip direction as an axis, and (*b*) about an axis also contained by the slip plane but perpendicular to the slip direction. The results

[47] Gough, Hanson and Wright, Phil. Trans. Roy. Soc. A, Vol. 226, 1926.
[48] See 8th Marburg Lecture, Proc. A.S.T.M., Vol. 33, Part 2, 1933, p. 53.

are shown graphically in Fig. 8, in which the ratio I/I_0 denotes the relative intensity of the reflection at the stated setting angle to that obtained from the setting giving maximum reflection according to the Bragg relation. These results show that the distortion of the slip plane is very much greater along the direction of slip than in the transverse direction; this general characteristic is exhibited by both the fatigue-stressed and the statically-stressed specimens, although the loading conditions were so different. Expressing this result in terms of crystal break-up (denoting a reduction in size of the crystal grains by a process in which the original grains are broken up into smaller fragments of differing orientation), the fragments appear to assume orientations which are mainly equivalent to small rotations about an axis contained by the slip plane and perpen-

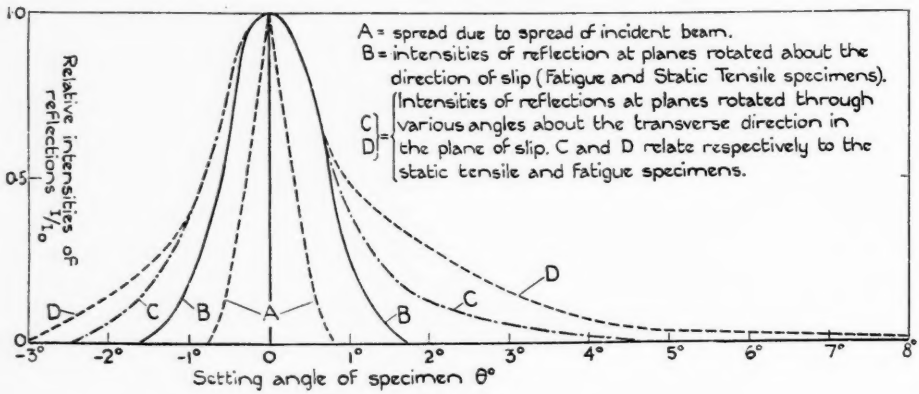


FIG. 8.

X-ray Evidence of Nature of Distortion of Slip Plane (Taylor and Gough).

dicular to the slip direction. It is difficult to conceive such a process operating without producing a considerable degree of local lattice distortion; this aspect was not, however, pursued further in the experiments referred to. However, it led one of us (H.J.G.) to suggest that the effect of plastic deformation on the slip plane might be to produce one or both of the effects indicated diagrammatically in Fig. 9, which relate to a section through a crystal perpendicular to the slip planes but containing the slip direction. Fig. 9(*a*) represents the transitory local curvature of the planes. Now this *might* mean that the structure itself is in a state of elastic strains as shown in Fig. 9(*b*), but it is difficult to conceive that such an arrangement would be stable. Neither is such a condition consistent with X-ray evidence. Much more probably the structure might have become broken up into small fragments, as indicated in Fig. 9(*c*), neighbouring fragments possessing crystalline form but being inclined to each other. In such a case, considerable strains (internal stresses) or actual sub-microscopic cracks must occur at the edges of such fragments. Now, if this difference in orientation increases with increasing severity of deformation, one can visualise that, at some stage of further deformation or further cycles of stress, the cracks would increase in size, spread through the material and cause complete rupture. The idea was particularly attractive for several reasons. In the first place, a method of crack-formation is rendered possible which could obviously occur under all types of stressing, consistent with the observed characteristics of failure of metals. Secondly, it possessed essential features entirely consistent with the X-ray observations of other workers—to which previous reference has been made—who had studied deformation characteristics of metals under cold rolling, drawing, etc.

For this reason it was decided to make a new attack on the fatigue problem, employing X-ray methods of precision, devoting special attention to the effect of stressing on the inner structure of metals. The results of this new research are described in the following section.

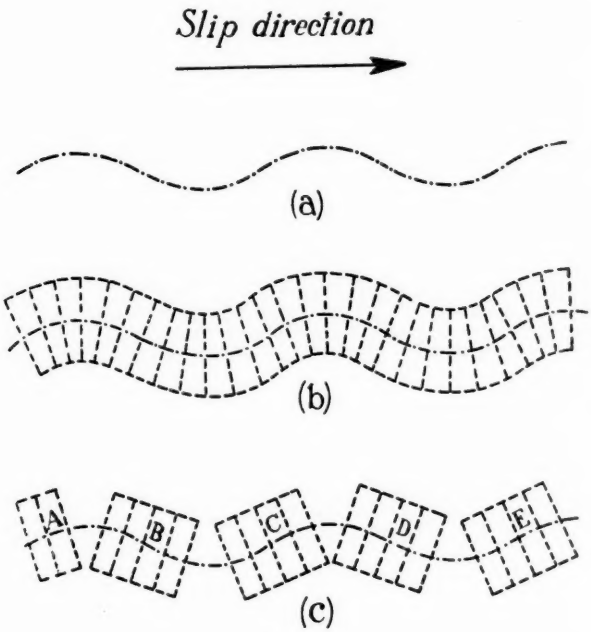


FIG. 9.

Diagrammatic Representation of Possible Effects of Slip on the Crystalline Structure.

VI. A NEW ATTACK UPON THE FATIGUE AND FRACTURE OF METALS.

In drawing up a programme of work, it was realised that single crystal specimens would probably supply the most direct type of information and be the simplest type to investigate. On the other hand, the study of the metal in the form of a polycrystalline aggregate is more intimately linked with practical conditions of service; it was therefore decided to commence with metal in this more usual form and to leave the single crystal for subsequent investigation.

The material used was a normalised mild steel having the following chemical composition: C. 0.12 per cent., Si. 0.185 per cent., Mn. 0.61 per cent., S. 0.012 per cent., P. 0.016 per cent., Ni. 0.06 per cent., Cu. 0.075 per cent. It was necessary that the material, in its initial condition, should be in an optimum condition as regards freedom from distortion; preliminary experiments showed that this was obtained following a careful normalising treatment consisting of heating at 950°C. for 15 minutes, followed by cooling freely in air at a rate, through the critical range, of about 20°C. per minute; this treatment was applied throughout. Not a little difficulty was encountered in reducing to a minimum and the final removal of the damage to the crystalline structure caused in the preparation of the test pieces; it is sufficient to record that this was accomplished by a lengthy machining technique consisting of 13 operations,

following by etching. Subsequent X-ray examination of each specimen failed to disclose any signs of deterioration of the state of the crystalline structure.

The actual experiments involved a great number of mechanical tests and X-ray examinations which went on continuously for about a year. It is pro-

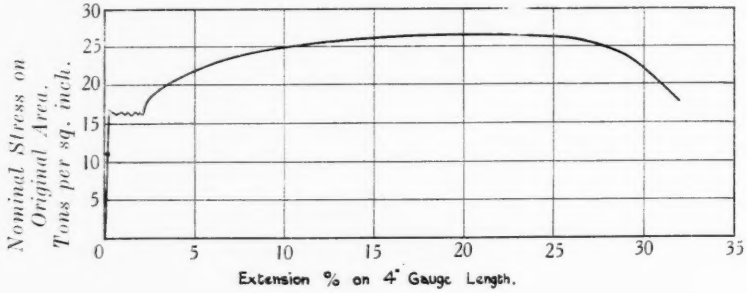


FIG. 10.

Tensile Stress-Strain Diagram (Dalby Recorder).

posed, however, to present the results in broad outline in order to concentrate on the essential new facts disclosed and to avoid these being submerged under detail. The individual history of each of the very numerous specimens is, of course, on record.[49]

Of the subsidiary mechanical tests (tension, compression torsion, etc.) it is sufficient to record the principal tensile test data: Limit of proportionality 10.9

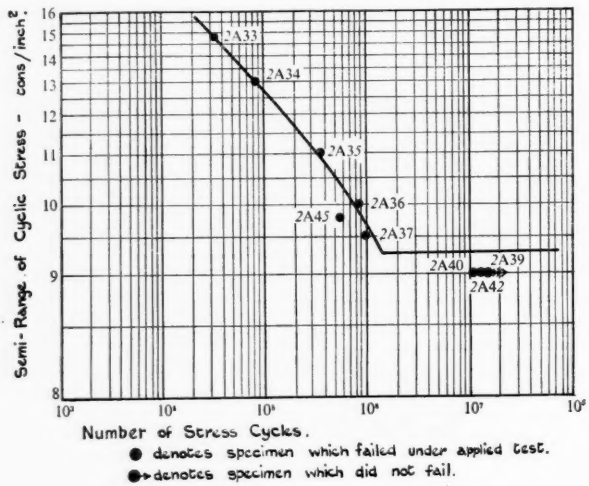


FIG. 11.

Results of Alternating Torsional Fatigue Tests (zero mean stress of cycle).

[49] "A new attack upon the Problem of Fatigue of Metals, using X-Ray Methods of Precision." H. J. Gough and W. A. Wood. Proc. Roy. Soc. A., No. 883, Vol. 154, pp. 510—539, May, 1936.

tons/sq. inch, yield stress 16.0 to 16.5 tons/sq. inch, ultimate strength 26.7 tons/sq. inch, elongation ($l=4/A$) $43\frac{1}{2}$ per cent., reduction of area $69\frac{1}{2}$ per cent. A typical autographic tensile diagram (Dalby Recorder) is reproduced as Fig. 10.

The essential scope of the experiments consists of a systematic study of the changes produced in the crystalline structure under various stressing actions and at various stages of each of these actions. Monochromatic X-rays and precision methods were employed throughout. Each specimen was submitted to X-ray examination at least on two occasions, *i.e.*, prior to and following the test; in many cases the test was interrupted for one or more intermediate examinations.

Three main series of fatigue tests have been made as follows:—

(1) Using cycles of reversed torsional stresses.
(2) Using cycles of reversed direct stresses (tension and compression).
(3) Using cycles of alternating direct stresses, in which the maximum stress of the cycle is maintained at a constant value of 20 tons/sq. inch which exceeds the static tensile yield point (16-$16\frac{1}{2}$ tons/sq. inch) of the material.

The results of these tests, expressed in the usual well-known form of "stress-endurance" curves, are given in Figs. 11, 12 and 13.

For comparison with the effects of fatigue stresses upon the structure, a study was also made of the progressive changes which occurred as specimens were strained to destruction under static-tensile and static torsional stresses. It will be sufficient to describe in some detail the method of examination of the tension specimen. It was first X-rayed in the unstressed state. Loading was then applied up to a nominal[50] stress of 5 tons/sq. inch. After maintaining the load for five minutes, the specimen was removed from the testing machine and its diameter re-determined by projection; it was then submitted to a further X-ray examination. This process was repeated successively, using various chosen values of nominal stress, until fracture occurred. It will be sufficient to record merely

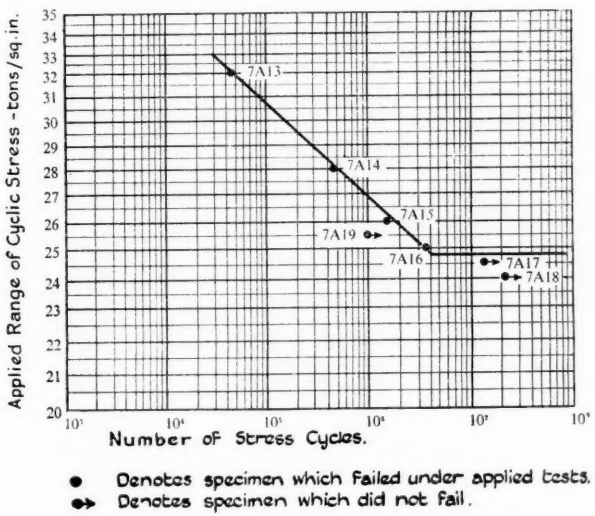


FIG. 12.

Results of Alternating Direct Stress Fatigue Tests (zero mean stress of cycle).

[50] Reckoned on the original area.

the applied nominal stresses, expressed in tons/sq. inch in the order they were applied, the figure given in brackets denoting the total percentage reduction in area of cross-section as deduced from the diameter measured after each test: 0 (0 per cent.), 5 (0 per cent.), 10 (0 per cent.), 12 (0 per cent.), 14 (0 per cent.), 15 (0 per cent.), 16 (2.2 per cent.; specimen yielded here), 17 (2.3 per cent.), 18 (2.7 per cent.), 19 (3.1 per cent.), 20 (3.5 per cent.), 22 (4.9 per cent.), 24 (5.0 per cent.); the specimen fractured at a nominal stress of 27.2 tons/sq. inch with a reduction of area at the fracture of 69 per cent.

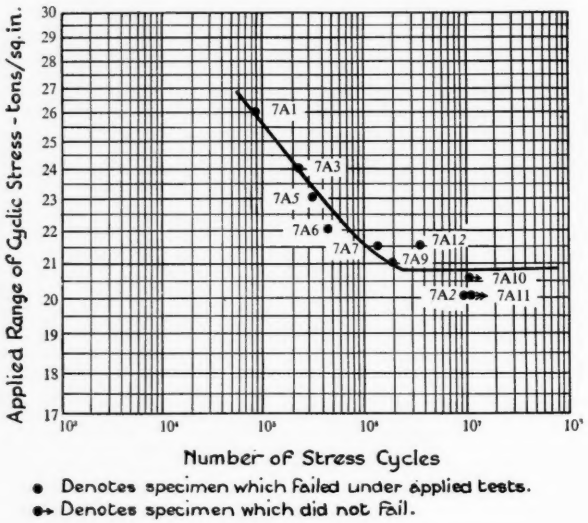


FIG. 13.

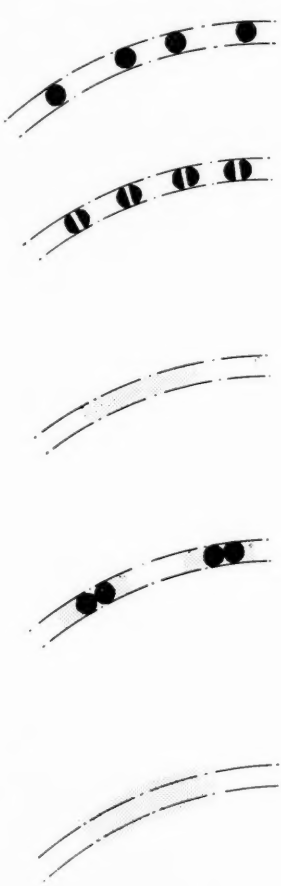
Results of Alternating Direct Stress Fatigue Tests:
Superior stress of the cycle held constant at 20 tons/sq. in. tension.

As it is now proposed to discuss the results obtained in relation to a series of a few typical X-ray photographs, the causes of some typical changes in X-ray spectra may conveniently be explained; for this purpose we may employ diagrammatic sketches given in Fig. 14.

Starting with perfect crystal grains, the X-ray photograph shows a series of sharp reflection spots, each of which is a reflection from the (211) planes of individual grains in the volume illuminated by the X-ray beam. The number of grains per cubic centimetre is proportional to the number of reflection spots (as described in Section II of the paper). With the mild steel used, the initial size of each grain was of the order of 10^{-2} cm., *i.e.*, there were approximately 10^6 perfect grains per cubic centimetre when the metal is in the original unstressed condition; this condition is illustrated in Fig. 14(1).

If the grains break up into smaller grains, each perfect and unstrained, more sharp spots appear and the ring tends to fill up. To denote such perfect smaller crystals the authors will use the term "dislocated grain." As the process proceeds, reducing the grain size from 10^{-2} cm. to 10^{-3} cm., the number of spots in the ring increases until, when a size of 10^{-4} cm. is reached, the ring becomes continuous. Fig. 14 (2) illustrates an intermediate stage before the continuous ring has been obtained. The following sketch—Fig. 14(3)—shows the final stage when the whole of the original grains have become broken up into small

perfect crystals. A complete diffused ring is obtained. The orientation of these crystals is entirely random. With regard to size, for the reasons given in Section II of the paper, the crystal size is *probably* not smaller than 10^{-4} cm., and is *certainly* not smaller than 10^{-5} cm., because the radial width of the ring



(1) *Original Undeformed Perfect Crystals.*
Sharp reflections: grain size $\simeq 10^{-2}$ *cm.*

(2) *Break-up into Smaller Crystals.*
Sharp reflections: grain size down to $\simeq 10^{-3}$ *cm.; slight differences in orientation of components; radial width of ring unchanged.*

(3) *Complete Break-up into Very Small Perfect Crystals.*
Entirely diffused and complete ring; random orientation; size probably not smaller than 10^{-4} *cm., certainly not smaller than* 10^{-5} *cm.; radial width of ring unchanged.*

(4) *Break-up into Sharp Spots with Diffuse Tails.*
Combination of break-up into smaller perfect crystals of 10^{-3} *cm., size slightly differing in orientation, together with a small volume completely broken down in* 10^{-4} *size; radial width of ring unchanged.*

(5) *Broadened Complete Ring: Fracture Stage.*
Structure entirely disintegrated in very small crystals in a state of internal strain; crystal size $\simeq 10^{-4}/10^{-5}$; *ring broadened but to a limited extent only.*

FIG. 14.

Diagrammatic Sketch Illustrating Principal Types of Change Occurring in X-ray Spectra due to Overstrain and Fatigue.

is unchanged; had the grain size become still further reduced, the lines would broaden out radially and finally become invisible, which did not occur. To this limiting small size (10^{-4}-10^{-5} cm.) of crystal fragment, the term "crystallite" is applied.

Actually, in the tests, a sudden change from Fig. 14 (1) to Fig. 14 (2) or Fig. 14(3) was *not* observed; the intermediate stage which always took place is represented in Fig. 14(4), which indicates the observed behaviour of any individual grain. The grain broke up into dislocated grains, each perfect and slightly tilted with respect to each other, producing an elongated reflection spot

(by the mechanism previously depicted in Fig. 4). But, simultaneously, these reflections also exhibited a misty " tail "—also in the direction of the circumference of the ring—indicating that a portion of the crystal had broken down into crystallites of the 10^{-4}-10^{-5} cm. size and having orientations which differed *widely* from that of the parent grain and of the dislocated grains.

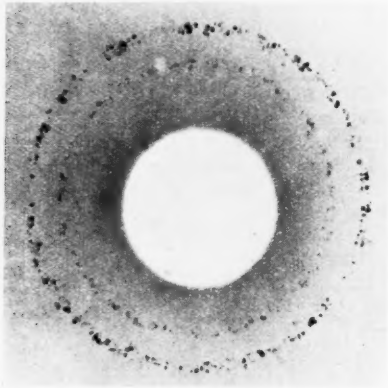


FIG. 15.
Unstressed material.

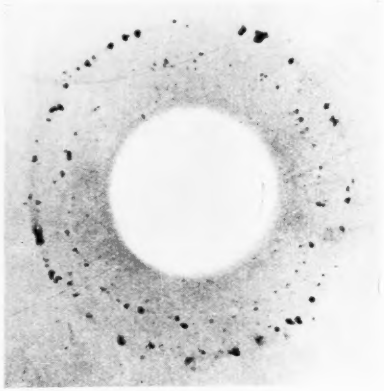


FIG. 16.
Static tension: 14 *tons/inch*^{2}.

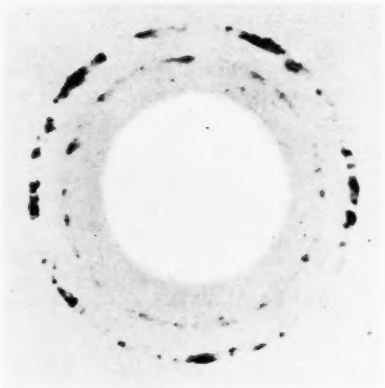


FIG. 17.
Static tension: 16 *tons/inch*^{2}.

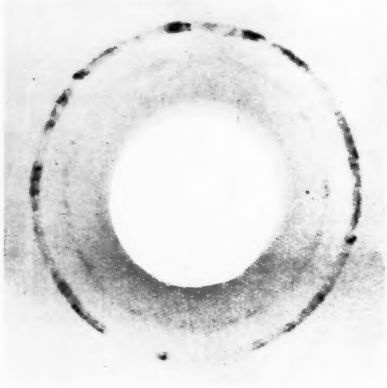


FIG. 18.
Static tension: 22 *tons/inch*^{2}.

The last sketch (5) of Fig. 14 indicates the condition (entire or local) of the structure at the fracture stage. The parent grains have become completely disintegrated into crystallites but, in addition, the ring has actually broadened radially to a certain limited extent. This radial broadening means that the lattice dimensions have been affected in an irregular manner, or, in other words, severe internal stresses are present.

We may now proceed to discuss typical X-ray photographs obtained during the research.

A. Effects on Crystalline Structure Caused by the Application of Static Tensile Stressing.

A typical X-ray diffraction photograph[51] of the material in the original unstressed condition is reproduced in Fig. 15; the ring is composed of separate

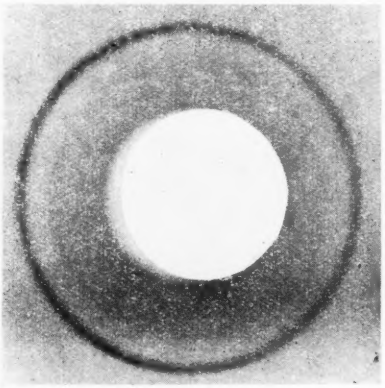


Fig. 19.
Static tension: 27.2 *tons/inch*^{2}
(*at fracture*).

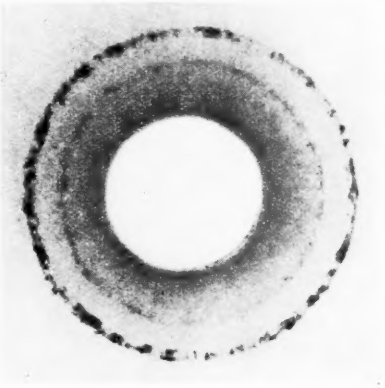


Fig. 20.
After yield in static torsion.

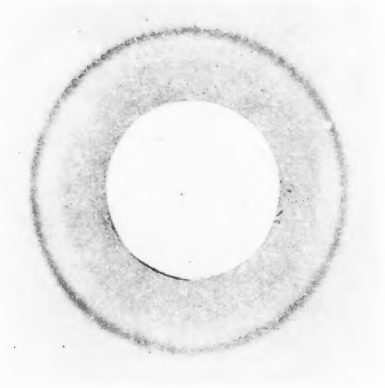


Fig. 21.
After fracture in static torsion.

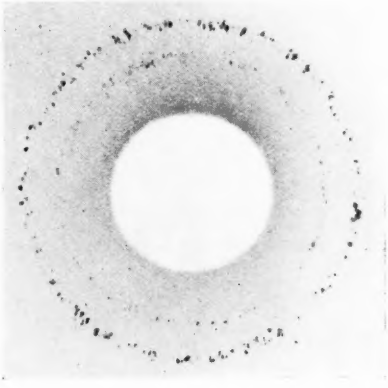


Fig. 22.
7*A*18 *R.D.* ±12.0 21.5 × 10^6 *U*,

sharp spots. No change occurred until the limit of proportionality of the steel was reached. Fig. 16, taken at 14 tons/sq. inch represents a stage intermediate between the elastic limit and the yield point. While it is generally similar to

[51] Hereinafter the term " photograph " will be used.

Fig. 15, there can be seen a trail of continuous line attached to one or two spots which have themselves become blurred. The first effect of static loading is thus to produce dislocation of an occasional grain together with a small amount of finely divided crystallites. At the yield point, the abrupt change, shown in Fig. 17, is produced. Every spot has become elongated along the ring to some extent, showing that *every* crystal has been dislocated into pieces tilted by 2° or less to the original grain; in addition, a faint continuous line stretches con-

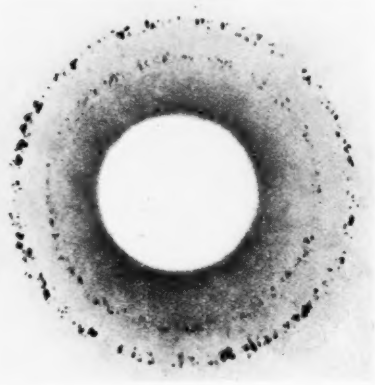


FIG. 23.
7A16 *R.D.* ±12.5 3.69×10^6 *C.*
(1) *At mid-section.*

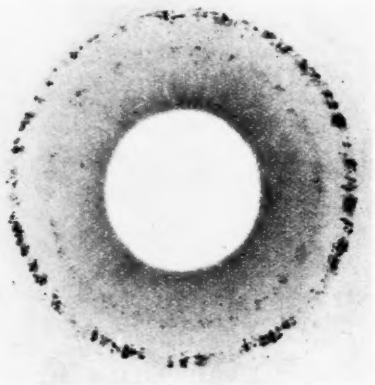


FIG. 24.
7A16 *R.D.* ±12.5 3.69×10^6 *C.*
(2) *Near fatigue crack.*

FIG. 25.
7A16 *R.D.* ±12.5 3.69×10^6 *C.*
(3) *At fatigue crack.*

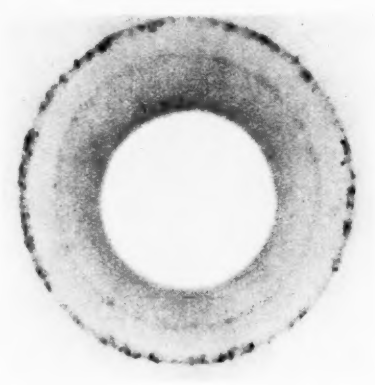


FIG. 26.
7A13 *R.D.* ±16.0 0.044×10^6 *C.*
Away from crack.

tinuously round the ring indicating an increased production of randomly oriented crystallites. As the loading was further increased, the elongation of the spots became more pronounced and the intensity of the continuous line increased. At fracture, *all* individual spots were submerged into a uniform diffuse continuous

line which indicated that the specimen behaved to the X-ray beam as a completely randomly-oriented system of crystallites each of which had suffered distortion of the crystal lattice. These changes are illustrated by Figs. 18 and 19.

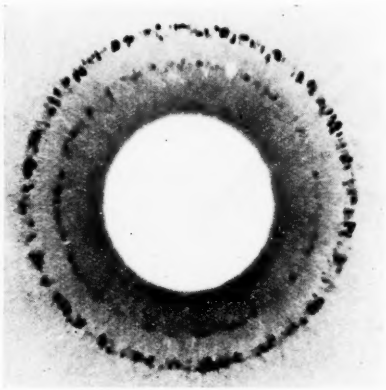


FIG. 27.
2.A45 *A.T.* ±9·7.
After 10^5 *cycles.*

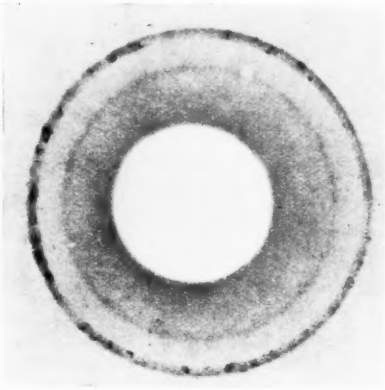


FIG. 28.
2.A45 *A.T.* ±9·7.
After $5{\cdot}57 \times 10^6$ *cycles (fracture).*

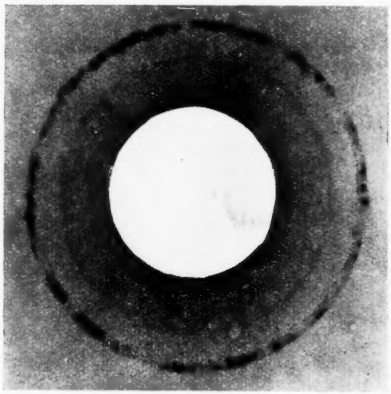


FIG. 29.
7.A4 *Static tension*: 20 *tons/inch*^{2}.

FIG. 30.
7.A10 *A.D.* +20/−0·5 10^7 *U.*

B. EFFECTS ON CRYSTALLINE STRUCTURE CAUSED BY THE APPLICATION OF STATIC TORSIONAL STRESSING.

The characteristics observed under static torsional stressing were essentially similar to those observed to result from static tensile stressing; it is, therefore, unnecessary to describe these in detail. Figs. 20 and 21 show photographs obtained after the yield point had been exceeded and at fracture.

C. Effects on Crystalline Structure Caused by the Application of Cyclic Stresses.

1. *Fatigue Tests using Cycles of Reversed Direct Stresses*[32] (*Tension and Compression*).

The stress-endurance curves of Fig. 12 show that the limiting fatigue range of the material under reversed direct stresses is clearly evaluated at 24.6 tons/inch^2, *i.e.*, ± 12.3 tons/inch^2.

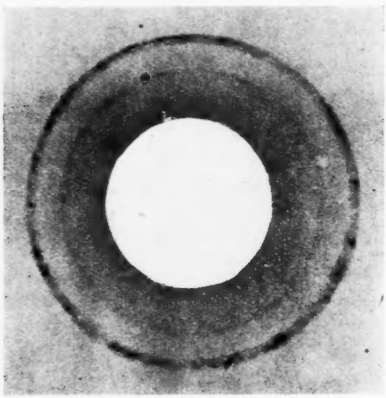


Fig. 31.
7A6 *A.D.* $+20/-2$ 0.44×10^6 *C.*

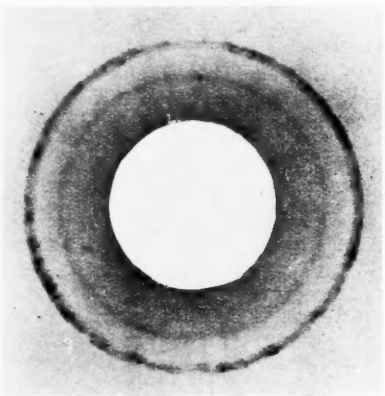


Fig. 32.
7A3 *A.D.* $+20/-4$ 0.22×10^6 *C.*

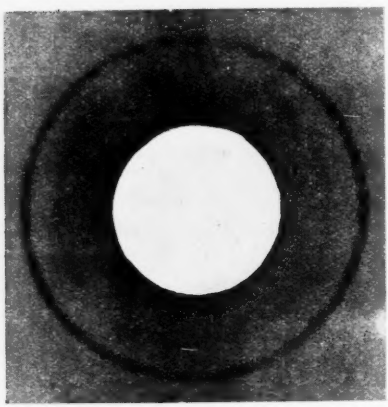


Fig. 33.
7A1 *A.D.* $+20/-6$ 0.09×10^6 *C.*

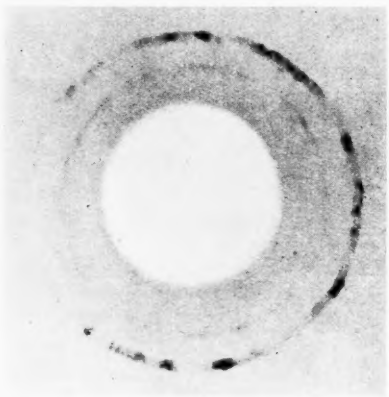


Fig. 34.
7A12 *A.D.* $+20/1.5$.
(1) *After* 10^3 *cycles.*

It was found first that the spectrum of specimens subjected to a safe range of stress showed no appreciable deterioration from that of the unstressed material;

[32] These tests were made using a Haigh electro-magnetic fatigue testing machine, operating at a speed of 2,000 stress cycles per minute.

the reflection spots are sharp and separated as shown by Fig. 22, which refers to specimen 7A18 which remained unbroken after subjection to 21.5×10^6 cycles of ± 12.0 tons/inch^2. But under an unsafe range of stress of any magnitude, marked deterioration occurred; specimen 7A16, tested at a range of stress *just* exceeding the safe range, is an excellent example. Fig. 23 is a photograph taken

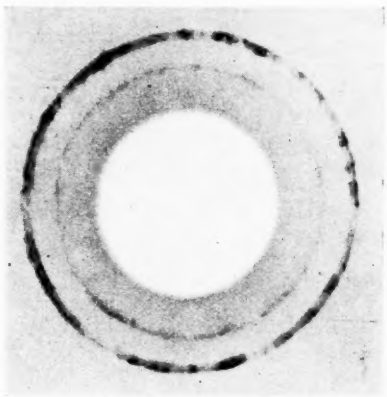


FIG. 35.
7A12 *A.D* $+20/-1.5$.
(2) *After* 10^4 *cycles.*

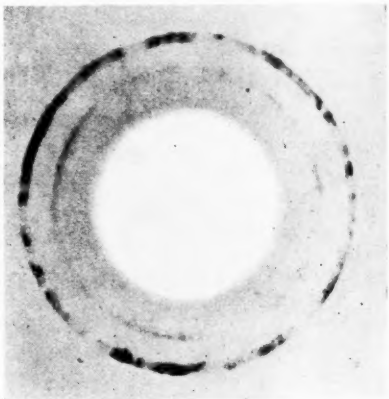


FIG. 36.
7A12 *A.D* $+20/-1.5$.
(3) *After* 10^5 *cycles.*

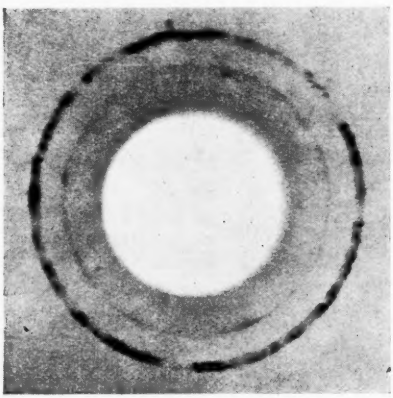


FIG. 37.
7A12 *A.D* $+20/-1.5$.
(4) *After* 10^6 *cycles.*

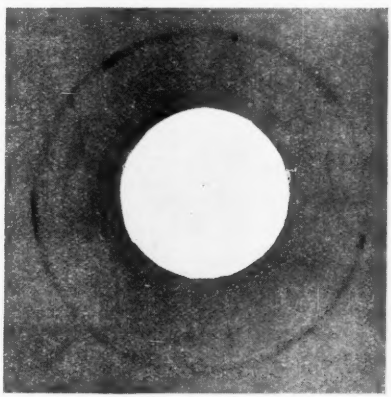


FIG. 38.
7A12 *A.D* $+20/-1.5$.
(5) *After* 3.85×10^6 *cycles C.*

at a position well removed from the neighbourhood of the fatigue crack. Counts showed that about 25 per cent. more reflection spots are visible than before test, while about 12 per cent. of the crystals had been entirely broken up into fragments. Many crystals, however, are practically unaffected, showing that fatigue is a local effect and offering an explanation of the well-known fact that, in general, fatigue cracks are confined to a relatively small number of crystals.

Fig. 24 is taken from the same specimen, but at a position nearer to the crack. A much greater proportion of the grains have become dislocated, while the intensity of the continuous ring is increased, showing the marked production of crystallites. Fig. 25 is taken *at* the fatigue crack; the majority of the crystals have become entirely fragmented, a few only being still visible in the dislocated state. It is also important to note that the continuous ring has increased in intensity and also broadened radially, indicating that the fracture stage is characterised by fragmented material in a state of severe internal strain. These three photographs are typical of the changes in structure occurring under *any* unsafe range of stress. A further important fact which emerged was that, as the excess of the applied range of stress over the safe limiting range increased, then an increased amount of deterioration of the structure was evident at every point in the specimen including points at a considerable distance from the crack; this is shown by Fig. 26, taken from specimen 7A13 at a position well removed from the fatigue crack, which should be compared with Fig. 23.

A study was made of the process of deterioration under an unsafe range of stress by interrupting the test on specimen 7A19 after 10^3, 10^4, 10^5 and 10^6 cycles had been endured. It was found that the main changes took place after 10^5 and 10^6 cycles, the spectrum after 10^3 cycles showing little change. After 10^6 cycles, the test was discontinued and the diameter successively reduced by etching. It was found that the structure at different depths from the original surface showed no divergence, showing that the fragmentation due to fatigue extends through the whole volume of the material and *is not a surface effect.*

2. *Fatigue Tests using Cycles of Reversed Torsional Stresses.*

The stress-endurance curves of Fig. 11 show that the limiting fatigue range under this type of stressing was clearly defined at $18\frac{1}{2}$ tons/inch^2 or $\pm 9\frac{1}{4}$ tons/inch^2 shear. The changes on the structure of each specimen were studied as for the alternating direct stress group referred to above; the results were precisely similar in type. Under millions of cycles of a safe range of stress, no appreciable deterioration was observed, while under any unsafe range, a progressive destruction proceeded as the test proceeded. It will be sufficient to record Figs. 27 and 28; these refer to specimen 2A45 tested at ± 9.7 tons/inch^2 and taken after 10^3 cycles and after fracture (5.57×10^6 cycles).

3. *Direct Stress Fatigue Tests in which the Superior Stress of the Cycle was maintained at a Constant Value (20 tons/inch^2 tension) which exceeded the Static Tensile Yield Point of the Material (16/16$\frac{1}{2}$ tons/inch^2).*

In the previous tests, the limiting range of stress was less than the static yield point of the metal and under any *safe* range of stress, no appreciable deterioration was caused to the structure; any changes which occurred under an unsafe range could be attributed directly to the action of fatigue. It was considered desirable to arrange other stress conditions capable of affording a critical examination of the capabilities of the X-ray method in discriminating between the effects of safe and unsafe ranges of stress where the effects of initial marked plastic deformation were imposed on the structure. A series of direct stress tests were, therefore, made in which the maximum stress of the cycle was maintained constant at a tensile stress (20 tons/inch^2) which exceeded the static yield point of the material (16 to $16\frac{1}{2}$ tons/inch^2), each specimen being cyclically *unloaded* from this value by a pre-determined range of nominal stress.

The results of the fatigue tests are shown in Fig. 13; the limiting range of stress was found to be 20.7 tons/inch^2, corresponding to a cyclical variation from 20 tons/inch^2 in tension to 0.7 tons/inch^2 in compression. Every specimen was examined in the manner previously described; some typical photographs will reveal the essential results.

Figs. 29 and 30 should be carefully compared. Fig. 29 shows the effects on the structure of a single application of a static tensile stress of 20 tons/inch^2; a marked deterioration has taken place (see Section V (*a*)). Fig. 30 shows the structure of specimen 7A10 after subjection to ten million cycles of a safe range of stress of 20½ tons/inch^2, after which it remained unbroken. It will be seen that this fatigue history had produced no further change in the structure than that caused by a *single* application of the maximum stress of the cycle.

Under cycles of an unsafe range of stress, however, a marked progressive further deterioration occurred. Part at least of the grains became completely fragmented. The greater the applied range was in excess of the limiting range, the greater was the extent of the damage and the more rapid the rate of deterioration. These characteristics are shown in the following photographs:—

Figs. 31, 32 and 33, show the final structure resulting from three unsafe ranges of stress. Specimen 7A6 (Fig. 31) shows a complete ring with a few reflection spots still persisting. In specimen 7A3 (Fig. 32), still fewer spots remain, while in specimen 7A1 (Fig. 33) the spectrum consists entirely of a complete ring, all reflection spots having disappeared.

We may conclude this account by a series of photographs which show the progressive changes which occur during the successive stages of the structure history of a specimen (7A12) subjected to cycles of a range of stress—varying from 20 tons/inch^2 tension to 1.5 tons/inch^2 compression—which just exceeded the limiting range. Photographs were taken after 1, 10^3, 10^4, 10^5, 10^6 and 3.85×10^6 cycles; these are reproduced as Figs. 34, 35, 36, 37 and 38. The structure after one cycle was precisely similar to that shown in Fig. 29. After 10^3 cycles, little further change can be detected; several grains were still not completely broken down, while the ring was not entirely continuous. As the cyclic history continues more and more grains become completely fragmented and at fracture practically the whole of the metal has been converted into crystallites of the limiting size and in condition of severe strain.

Thus, the X-ray method has proved entirely successful in discriminating between the effects of a safe and unsafe range of stress under the most unfavourable conditions.

VII. General Conclusions Drawn from the Present Research.

A. Conditions of Structure.

Whatever type of stressing has been applied—torsion, tension or compression, static or fatigue—the effect on the structure is one of destruction of the crystals producing material always in one or more of three conditions:—

(*a*) *Perfect grain* giving a sharp X-ray reflection; has same orientation throughout; size 10^{-2} cm.

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(*c*) *Crystallites.*—Very small crystal fragments giving reflections in form of sharp line extending farther round ring than elongation due to dislocated grain. Wide variation in orientation. Grain size is of order 10^{-4} cm. to 10^{-5} cm. A tail of such reflections attached to a strong reflection from a dislocated grain indicates that some widely oriented crystallites form simultaneously when a perfect grain is dislocated; probably at the boundaries of the dislocated grains.

B. Sequence of Events under Static Stressing to Fracture.

(*a*) *Within elastic range*: No change in perfect grains.

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With increasing stress, dislocation proceeds with production of larger proportion of crystallites.

(*d*) *At breaking point*: Metal consists *entirely* of randomly-oriented crystallites. At this stage, the diffraction ring broadens which probably means strain distortion of the atomic lattice. Fracture probably occurs when a limiting distortion is reached.

C. Sequence of Events under Fatigue Stressing.

Two stress factors are of major importance, (i) the maximum stress of the cycle, (ii) the range of stress. At the *first* application of the maximum stress, some damage by break-up is caused to the structure; this damage may vary from zero to any value of destruction.

The *safe range* or *fatigue limit* is the maximum range which will cause no further progressive break-up; no change is caused by any number of cycles of a safe range of stress.

If the applied range of stress *exceeds* the safe range, progressive deterioration and break-up into crystallites sets in leading to fracture exactly as in a static test to destruction. The greater the range of stress, the greater the *total* number of perfect grains totally destroyed and the fewer the number of cycles required to produce complete fracture. Hence the familiar form of the S/N curve. But in every case, the same final condition of destroyed structure is reached in the region of the crack.

It is considered that the experiments described give the first physical explanation of what fatigue really is. In addition, they show clearly that the fracture of metals under statical and fatigue stressing is accompanied by exactly the same changes in structure.

These results afford no explanation of one of the essential phenomena observed. We require to know the *reason* why the crystal grains break up into very small fragments of a certain limiting size, between 10^{-4} and 10^{-5} cms., and apparently refuse to break down further under the diverse stressing systems investigated. But, as we have seen in Section III of the paper, strong evidence of the existence of an inherent system of imperfections in crystals is now accumulating from various independent sources and we may hope, not unreasonably, that the causes of this system will become established. The new facts, of a quantitative nature, made available by the present experiments may be helpful in arriving at a clearer understanding of this interesting fundamental aspect of the strength of materials.

Discussion.

The Chairman: The members of the Society had listened to a lecture on a scientific aspect of some of their day-to-day problems. As aeronautical engineers they were always seeking better and better materials; they wanted light materials and they wanted those materials to be very strong, and on the whole they had been well served by the industry. For instance, the mechanical properties of the alloys containing aluminium as their main constituent had been most notably increased. The aeronautical engineers were, of course, not satisfied, and they wanted more; they wanted better aluminium alloys, they wanted better magnesium alloys, and he imagined that they wanted to reach the point that had been reached by the electrical engineers, who, when they wanted to design a dynamo, for instance, would combine things about which they knew and would obtain a result upon which they knew they could confidently rely. At present, if one asked the metallurgists to provide a material to a specification, believing that they knew enough about lattice structures, and so on, to be able to build it up by design as the electrical engineer built up a dynamo, they would say that the state of knowledge was not yet sufficient to enable them to do that. But the light was coming gradually and, in addition to knowing what gave the alloys

their particular properties, one needed to know what were the causes of the failures of the material under the stresses imposed upon it. It was to that latter aspect of the question particularly that Dr. Gough and Mr. Wood had been directing their exposition. They had mentioned the work of many others in that field, including that of two Englishmen whose work was well known to the members of the Society—Professor Geoffrey Taylor, of Cambridge, and Mr. Griffith, whom the Air Ministry was fortunate enough to have among the staff at Farnborough. They were beginning to acquire knowledge on these subjects. In regard to the manner in which materials failed they were certainly very much further ahead, thanks to the work of Dr. Gough and his colleagues, than they were in regard to the design of alloys for a specific purpose.

A paper of the kind that Dr. Gough and Mr. Wood had contributed, dealing with general considerations, was very welcome to the Society, because aeronautical engineers needed the shedding of more light on their problems from an aspect other than that from which they were accustomed to regard them; from the National Physical Laboratory they were accustomed to receive those rays.

Mr. J. L. Hodgson (*Associate Fellow*): How were the X-ray photographs shown in Figs. 15 to 38 taken? Were they reflections from a polished surface of sheet metal? Also whether one could take a photograph and afterwards continue the stressing.

Did research on the lines described indicate any possibility of producing materials of enhanced strength there owing to their greater perfection in atomic structure?

Mr. H. Sutton (Royal Aircraft Establishment) (*Fellow*): He had been in fairly close touch with some of the authors' research work as it had proceeded, and the kind of information they had brought forward in the paper was undoubtedly, as the Chairman had mentioned, of the kind to which they could look for assistance in ascertaining the reason for the limitations of many of their known materials and perhaps in improving them.

In asking what was the effect of under-stressing, from the point of view of the inner structure, Mr. Sutton said it was fairly commonly believed that during the time in which a test piece was under test in the fatigue testing machine at a load below its limit, in air, its fatigue properties were being slightly raised. He asked for their impression as to what might be happening to the inner structure during the loading of the specimens at alternating or fluctuating stresses below the fatigue limit. He also asked whether they had had experience of metals and alloys other than those mentioned in the paper in regard to the effect of stresses upon the inner structure. For instance, the fatigue limit of some of the light metals, such as the magnesium-rich alloys, appeared to fall steadily with increasing time of endurance. Many of the magnesium-rich alloys, tested in air, appeared to give fatigue curves more or less in the nature of a straight line, the fatigue limit becoming lower the longer the life of the specimen. He asked whether the authors had yet applied the X-ray eye to that particular aspect of the problem.

The subject of fatigue and corrosion was also of very great interest. Largely as the result of the work of Dr. Gough and his excellent team at Teddington, they knew that corroding agencies reduced the fatigue properties of materials very substantially, and it would be interesting to know whether corrosion at the same time as fatigue showed itself in any remarkable way in the X-ray pictures.

Mr. Sutton added that he had been impressed by three perhaps different, but related, endeavours which had been made in the practical field to improve the fatigue strength of ordinary engineering materials. First, there was the nitriding of steels, which appeared to improve the ordinary fatigue properties, and in that case there was a hardening of the skin accompanied by an increase of volume. Nitriding appeared to cause fatigue fractures to start well below

the surface. Improved fatigue properties had been found to occur in ordinary carbon-case-hardened steel specimens.

He believed it was found in specimens which had been work-hardened on the surface in the manner suggested by two German investigators, Föppl and Thum. He asked for the authors' remarks on that particular aspect of improving the strength of quite ordinary materials.

Mr. P. A. STEPHEN: One of the problems in connection with light alloys and age hardening was the occurrence of high internal stresses, the amounts of which were not known. If the phenomenon occurred in the age-hardening alloys and the grain size were favourable, it might be possible to decide by means of X-rays whether the fatigue range had been passed. If it were known that a material had not been stressed beyond the normal fatigue range, the difference should be due to internal stress. If that were so, it suggested a very important experiment of vital interest to the aircraft engineering concerns.

Mr. W. O. MANNING (*Fellow*): With reference to a remark in Section VI of the paper, that with the mild steel used, the initial size of each grain was of the order of 10^{-4} cm., said that, after straining, the whole of the original grain was broken up into small perfect crystals, and the steel in that state was badly strained; he gathered that imminent fracture might then be expected. On the assumption that it was possible to produce steel with those small perfect crystals in the first place, he asked what mechanical properties would be expected from it. Would the mechanical properties be better than those of the steel used originally, or would they be such that the steel was likely to fracture after a very small number of reversals?

Following from that question, and taking the steel to which the authors had referred, he asked whether it would be possible to specify theoretically—without reference to whether or not it was possible to make it at the present moment—the ideal arrangement of crystals in that material to secure the best possible mechanical properties. Would the material have only one crystal, or, if there were more than one, what should be the size of the crystals and how should they be arranged? It might be quite impossible at the moment to make such material, but the information he had asked for would be very useful, for it would at least give the steel manufacturers something to aim at.

Mr. I. J. GERARD (*Associate Fellow*): He asked whether the particular methods of attack described by the authors might reduce the amount of time occupied in the determination of fatigue range. The authors, he said, represented a world-famous team, and they knew only too well that ordinarily fatigue investigations occupied a long time, it being necessary to apply millions of cycles of stress. If their work would reduce the time occupied by such investigations it would be an important advance in the technique of fatigue testing.

In many cases, he continued, one started with a material in a particular condition, and, after it had been submitted to a number of cycles of stress, the mechanical properties changed. There might be a hardening effect or there might be a re-distribution of stress. He asked whether new light was being shed on what was actually happening in such cases.

Mr. W. E. WOODWARD (Cambridge): He wondered whether the X-ray work would shed any light on the fact that materials which had been over-strained exhibited a higher yield point after having been rested for a week or two or after having been boiled for five minutes. If there were breakdown of crystals immediately after the material had been stressed beyond the yield point, X-rays might show whether any healing of the distorted grains had occurred.

Mr. J. L. HODGSON (*Associate Fellow*): He drew attention to the belief that as the result of work-hardening, the crystals actually melted and later they sealed together again. He asked whether X-ray analysis proved or disproved that belief.

Mr. E. T. Sargent: Other things being equal, was there any atomic change in the structure of steel from the point of view of age only, in any re-arrangement of crystals, or any other way, as he believed happened in the case of glass?

Reply to the Discussion.

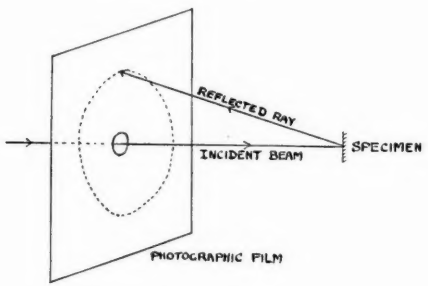
Dr. Gough replied to some of the points raised in the discussion, and left others to Mr. Wood. Dealing first with Mr. Hodgson's question as to whether the knowledge put forward in the paper helped us towards achieving the ideal, he said it was definitely a link in the chain. When we knew exactly not only the manner in which the materials broke down, but also the reason why the secondary structure existed, he believed we should have the complete answer. The research described in the paper had not yet given a complete answer, but it represented a stage in that direction.

He did not think the idea was accepted that during slip the material actually melted at the slip planes, and the authors had not found any evidence of melting in the crystals. He believed the idea of melting had arisen from the engineers' conception of friction, because there was movement.

Mr. Hodgson: He believed the physicists had that idea also.

Dr. Gough: At any rate, the authors had seen no evidence of it.

Mr. W. A. Wood: Replying to Mr. Hodgson's question as to whether the X-ray photographs were reflections from a polished surface, and what was the nature of the specimen and its general disposition, he explained that the X-ray beam was limited by the slit system to a narrow pencil, which was allowed to fall on to a fatigue specimen of the usual shape. The beams reflected from the grains in the specimen were collected on a photographic film which was perpendicular to the X-ray beam. The film was pierced at the centre in order to allow the beam to pass through, and that was the reason for the central disc in the photographs; the beam passed through the hole and hit the surface, and the reflection was recorded. The surface of the specimen was etched very carefully in order to remove any superficial effects which might be produced by polishing or by workmanship; great care had been exercised in the preparation of the material. (He illustrated the photographic method by means of a sketch.) A specimen might be photographed at any stage during the application of stress.



Dr. Gough: The question of the effect of under-stressing upon fatigue, raised by Mr. Sutton, was very important; the effects to which Mr. Sutton had referred were probably well known, but were extraordinarily interesting. Taking the ordinary $S-N$ curve, if one stressed some materials for a long time within the safe range and then increased the stress by increments, one could obtain a considerable increase in the fatigue range.

The authors had, as yet, no information on the cause of under-stressing as shown by X-rays; but they had noticed that, when a specimen had been subjected

for a long time to a stress within the safe range and was then allowed to rest, there were slight signs of recovery, the structure tending to revert a little towards its original condition. It might be that the recovery was in the nature of some form of re-crystallisation, and that one could coax the material by some process of re-crystallisation so that the under-stressing effect was accounted for. However, at the moment, that was merely surmise; it was hoped to make some experiments on this interesting aspect.

The authors had not completed any work on materials other than those mentioned in the paper, but they were, at the present time, working on a brass, which was one of the materials which Mr. Sutton had in mind, he believed. The work had not yet proceeded sufficiently far, however, to enable them to refer to it with certainty. Again, they had not carried out any experiments on the effects of corrosion upon the X-ray pictures, nor with regard to nitriding.

Replying to Mr. Manning's question as to what mechanical properties would be expected of material initially in the crystallite stage, Dr. Gough said he did not know, but he supposed one would expect to get the same tensile strength, for example, because if one started with the material in the final condition there was no reason why the strength should be different. Certainly, however, one would expect the material to be almost entirely devoid of plasticity as he imagined that there would be no available slip planes left.

He did not think it was possible to specify the optimum number of crystals in a metal. He believed engineers in general would agree that, in a material for engineering purposes, of good strength properties ductility, a close-grained aggregate with uniform grain size was generally the ideal at which to aim. He and his colleagues had been trying to work from the other end, starting from the single crystal and proceeding to specimens containing two, three, four, five, six and seven crystals; so far as they could tell at the moment, there was very little difference in strength as between specimens containing one and seven. But that was only a very small part of the story, because in the aggregate there were usually a million crystals to the cubic inch. So that that would not give much information in answer to Mr. Manning's question.

In reply to Mr. Gerard, Dr. Gough considered it quite possible that one could develop a method of X-ray examination to determine the fatigue range, but he was not at all sure that it would result in any saving of time. At one time he had thought that a method other than the endurance method for determining fatigue range would be desirable; so far, the methods tried had not proved successful in being entirely reliable, but, even if they had been successful, the time and the money involved in their application would be greater than was involved in using three or four fatigue testing machines, which would give, not a complete answer, but a very good answer within three or four days. He did not think the determination of the fatigue range would be more satisfactory by taking X-ray pictures, having regard to the time and the cost involved. However, that was merely an opinion, for the authors had not tried it.

Dealing with Mr. Woodward's question as to whether X-ray work had shed any light on the effect of boiling or resting specimens of over-strained materials, Dr. Gough recalled the stress-strain curves obtained during a static test by a load exceeding the yield point and the cyclic stress-strain curves obtained as the result of a succession of loadings and unloadings, and said that in time, if the stress were not too high, a cyclic state would be established; that required a large number of cycles. The X-ray photographs showed how such a cyclic state was established and, although not carried out with respect to the recovery achieved by resting or boiling, no doubt the same essential process was involved. In the authors' work, using 20 tons maximum tensile stress, in some cases they had placed the specimen in the machine, had applied a safe cycle of stress and had obtained that sort of result. In other cases they had first applied the 20 tons stress as a static loading, had then X-rayed the specimen and then placed it in the fatigue testing machine; but, having once obtained a certain

extension at 20 tons static load, there was no further extension when the specimen was put back into the Haigh machine. In other words, the sort of creep that occurred in a specimen in a fatigue testing machine was not inherently due to the different effects of the two methods of test, but merely due to the suppression of plasticity at the high working speed of the fatigue machine. That was a new observation which had very much impressed the authors. They had also investigated higher values of stress; they had stressed a specimen up to 26 tons, the ultimate breaking strength being 26½ tons, and in that case obtained a wonderful example of the suppression of plasticity in a high speed fatigue testing machine. Sometimes it would require five minutes for the total strain to be developed. When a specimen had been fully strained and then taken out of the machine and put back again, no further extension occurred under the same maximum load, provided it was associated with a *safe* range of stress.

Mr. Wood, replying to a question as to the possibilities of using X-ray photographs to show changes of structure, said that it was quite possible and would be very useful. The changes which it was most easy to detect were, first, break-up of the grains; secondly, changes in the size of the lattice; thirdly, distortion of the lattice; and lastly, any changes that occurred in the chemical composition of the material, which information was useful in the case of complicated alloys, where there might be changes in the degree of homogeneity of the material from point to point.

The question raised by Mr. Gerard with regard to hardening involved a point which had been studied for some time in the Physics Department of the National Physical Laboratory. It was that if one deformed a material, say, by cold working, there was a progressive breakdown of the grain into crystallites, as was shown by the photographs. But that process did not continue indefinitely; there was a certain change in the early stages and then it approached a maximum, suggesting that there was a limit below which it was not easy to break down the crystallites. The hardening changes occurred in that early stage when the production of the crystallites was most marked. If by any chance, in a given metal, one could get the crystallites into the region below the apparent limit, a tremendous increase of hardness was obtained. (That brought in the point raised by Mr. Sutton with regard to nitrided and case-hardened steels.) The agency used in those cases was an extra chemical agency which apparently was preventing the growth of the crystallites; the production of this fine structure was shown in the X-ray spectrum by a change from the normal sharp reflection ring to a very diffuse type of ring. Fig. 7 in the paper provided an example, not of nitrided steel, but of chromium plate. By electro-deposition, of course, one could obtain chromium in a very, very hard state, and Fig. 7 (*c*) and (*d*) showed the difference between X-ray diffraction rings from partially normalised chromium and chromium as electro-deposited, there being great diffusion in the latter case. In the case of the nitrided steels, the diffusion was even more marked; one could trace it as one proceeded through the case-hardened layers to the soft core, noting the changes as the hardness changed.

One could, in certain materials, follow changes due to ageing by means of the spectrum. That had been attempted by Preston and Gaylor with duralumin, but a great deal of work had still to be done on that problem. He had taken some photographs showing changes in steels due to ageing, the changes in those cases being due usually to the growth of carbides which had come out of the lattice; one could trace the difference between the original stage, in which the carbides hardly appeared, and the final stage, in which they quite definitely appeared, showing that a " chemical " change had occurred.

On the motion of the Chairman, the thanks of the meeting were heartily accorded the authors of the paper.

METALLURGICAL PROBLEMS OF AERO ENGINE MANUFACTURE.

(A paper read before the Bristol Branch.)

By E. R. GADD, Esq., Chief Metallurgical Chemist to the Bristol Aeroplane Co. (Engine Department).

The modern internal combustion engine, particularly the power unit developed for aircraft propulsion, provides a subject of great metallurgical interest and speculation.

The requirements of the aero engine designer for greater engine power while retaining a low weight/power ratio has inspired research into fuels of improved characteristics, and on the metallurgical side into materials of superior properties to those previously available.

I do not propose to enter into any detailed description of the recent important developments in fuel research, as this is outside the scope of the present paper.

The production of high anti-knock fuels has, however, introduced certain problems of metallurgical importance, which will be dealt with later in this paper.

Not many years ago very little published data was available giving the physical properties of materials of even established engineering use. Such data as was available dealt mainly with mechanical strength and hardness.

Nowadays, when the engine designer is considering the value of a material for a particular component, he may require to know a great deal about its chemical and physical characteristics before he can decide whether the material will suit the purpose intended.

He may require to know, for instance, particulars of any or all of the following properties:—

(1) Tensile strength at normal and elevated temperatures.
(2) Fatigue strength at normal and elevated temperatures.
(3) Specific gravity.
(4) Hardness.
(5) Rate of expansion under heat.
(6) Resistance to abrasion.
(7) Heat conductivity.
(8) Resistance to corrosion and scaling.
(9) Resistance to fretting and warting.
(10) Structural stability under prolonged heating conditions.
(11) Resistance to repeated impact stress.
(12) Susceptibility to internal stress, produced by manufacturing processes.

It should be also added that the material should be capable of being produced commercially and of being machined or worked with reasonable ease.

It will be seen at once that the metallurgical aspects of aero engine construction cover an extremely wide field, and it is hardly necessary to lay emphasis on the advantages to be gained by having at the disposal of the designer a chemical and metallurgical laboratory capable of readily supplying any such information as may be required.

The modern works metallurgical laboratory needs to do a great deal more than collect and record published data on materials and to do the routine production testing. Published data and information on such things as fatigue strength, creep strength, expansion properties, etc., are still somewhat scanty,

and that which is available very seldom happens to give just the information required to solve a particular problem.

For this reason it is found necessary to do a great deal of metallurgical research work and testing in the engine works' own laboratory, and in this respect I am proud to be a member of a firm who have realised this necessity, and have not stinted in their efforts to provide excellent laboratory accommodation and equipment.

It is impossible, in a paper of this length, to deal with all the metallurgical problems which arise in the course of engine development and construction. They occur almost daily, and many are of an uninteresting and mediocre character. Others, however, may be of fundamental and far-reaching importance, and it is to these that I wish to refer in some detail.

It occurred to me that the best way to tackle the problem of setting out this subject in simple and readable form, was to select a number of the more important components of the aero engine, indicating the metallurgical properties required and showing how the materials now used have been evolved or selected for their specific purposes. It will be observed, when considering these various cases, that continual reference will be made to the physical and mechanical properties set out in the earlier part of this paper.

Crankshafts, Connecting Rods, High Tensile Bolts, etc.

Table I gives details of the mechanical properties of the more important high tensile steels which have been used for such parts as crankshafts, connecting rods, highly stressed studs, bolts, etc.

There are certain portions of the engine construction which for fundamental reasons must be constructed in steel. Crankshafts and connecting rods, for instance, must have high tensile strength, fatigue strength and stiffness. These properties cannot be adequately supplied by the non-ferrous alloys.

A glance at Table I will show that while such steels as S.11, S.65 and S.81 give reasonable fatigue strength, the best figures are obtained with S.28, case-hardened S.82 and nitrided D.T.D. 228.

In considering these steels for crankshafts or connecting rods, however, attention has to be given to manufacturing difficulties. S.28, for instance, after heat-treatment has a tensile strength of 100 tons sq. in., rendering any finish machining operations extremely difficult. By very careful processing, however, connecting rods are being satisfactorily made in this material.

The selection of a crankshaft steel may be influenced by the fact that it is found desirable to have a high surface hardness on the crankpin, which assists in reducing main bearing frictional resistance. This is desirable when white metal bearings are used, and still more so with lead bronze bearings.

Case-hardening of the crankpin only is frequently adopted, although it is obvious that it might be desirable from fatigue characteristics to case-harden the complete surface of the shaft. The production of such a shaft is difficult because the quenching of the part occasioned by the case-hardening process will produce distortion, making the maintenance of uniform case thickness extremely difficult.

The nitrided shaft, howeved, offers great possibilities, since there is little or no distortion produced by the nitriding process. It has been found possible to finish machine crankshafts and nitride them all over, leaving a slight grinding allowance on the crankpin only. The surface hardness produced, while not being so high as that obtained by case-hardening, appears to be adequate for use with the bearing materials mentioned above.

In considering steels for highly-stressed parts, due consideration must be given to the fact that some steels are more sensitive to stress concentration than others. High tensile steels of the S.28 type come under this category. On the other hand, contrary to what one would expect, case-hardening and nitriding appears to reduce the susceptibility to notch sensitiveness.

PISTONS, CYLINDER HEADS AND ALUMINIUM ALLOYS FOR HIGH TEMPERATURES.

The piston and cylinder head are important parts of the aero engine, inasmuch as they have to combine lightness with good strength up to 350°C. and good heat conductivity. The piston, in addition, should be capable of developing a good surface in contact with the cylinder barrel. All the alloys given in Table II, with the exception of S.32, have expansion coefficients of the order of 0.000024 per °C. This is a disadvantage in that the cylinder barrel is usually a steel with an approximate expansion figure of 0.000012 per °C. This discrepancy in expansion between the piston and cylinder means that in order to maintain good bearing contact at working temperatures the cold clearance is excessive, causing considerable piston slap during the warming up period, with risk of seizure or other damage.

The S.32 alloy has a somewhat lower expansion figure, but this is offset by its lower mechanical strength at elevated temperatures. In regard to the relative merits of cast and forged pistons, there is an increasing tendency (and a right one in my opinion) to use forgings. Apart from the great advantage of obtaining

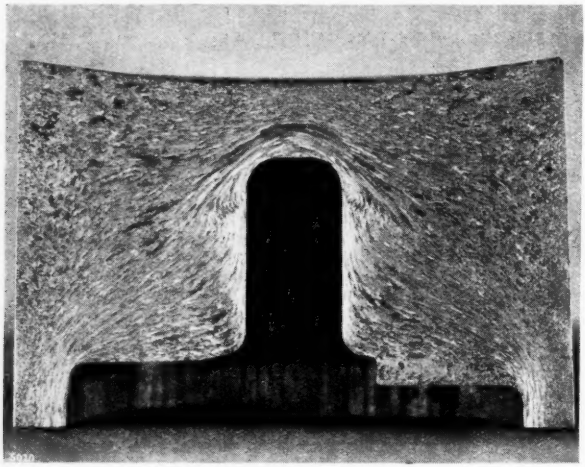


FIG. 1.

Grain flow in forged pistons.

correct directional grain flow at the highly stressed parts of the piston, the forged piston permits of the production of an article of greater uniformity and freedom from defects than is possible with the cast piston (Fig. 1).

In regard to surface bearing properties, both the R.R.59 and S.32 alloy types are superior to the " Y " alloy or 3.L.11. The latter alloy is in any case ruled out by reason of its strength at temperature.

A consideration of the above facts will reveal that R.R.59 gives the best all-round results, and in fact is widely used in this country for aero engines. The S.32 alloy has many adherents in the United States, its lower strength properties being counteracted by ingenuity in design and attempts to provide a large cooling surface on the underside of the crown.

With the present engine performance requirements, however, it becomes increasingly obvious that the present materials available for pistons have not an adequate margin of strength at working temperatures. While the designer has, by clever design, been able to produce a piston satisfactory for present needs, new alloys of greater strength are urgently required, and much investigation

on these lines is being undertaken by the metallurgists of the aluminium alloy producers. The cylinder head has much in common with the piston, especially in regard to strength at elevated temperatures, lightness and heat conductivity. The question of bearing properties does not however arise, so that it need not be similar to the piston in composition. The expansion coefficient is also not quite so important. Forgings are desirable for the same reasons given above for pistons, so that the choice falls on R.R.59 and " Y " alloy. There is probably little to choose between these alloys for cylinder head use. " Y " alloy appears to offer certain advantages in regard to its ability to maintain its Brinell hardness at a higher level after prolonged exposure to temperatures in the region of 350°C. (Fig. 2). This feature will be appreciated when one considers that the valve seat inserts are held in position by an interference fit produced by a shrinking operation. The maintenance of the hardness of the surrounding aluminium head material under conditions of prolonged and repeated heating is very desirable.

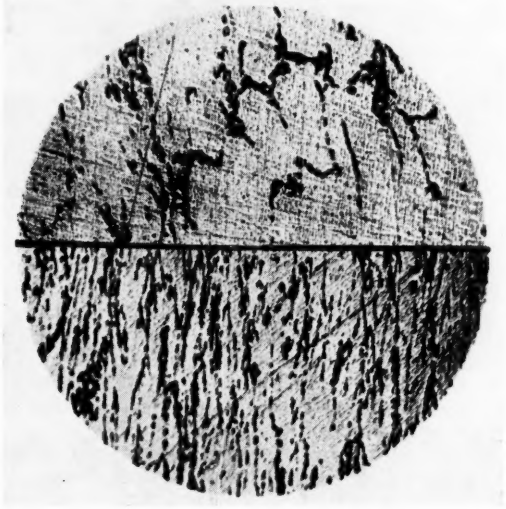


FIG. 2.
" Y " *alloy after prolonged heating.*

VALVE SEAT MATERIALS.

One of the first essentials of the valve seat insert is that the expansion coefficient should approximate as near as possible to that of the head material. This immediately restricts the types of alloy which can be used to those of the bronze, brass or austenitic steel families. The properties of typical alloys of these groups are shown in Table III.

This question of high expansion applies to both inlet and exhaust seats. The exhaust seat transmits the heat from the exhaust valve to the head, the quantity of heat so dissipated depending on the maintenance of good metallic contact between the seat and the head.

The inlet seat, on the other hand, tends to remain comparatively cool, the head material expanding away from it due to heat received from the combustion chamber. The inlet seat must, therefore, be of a material of high expansion characteristics, and in practice it is usual to give a greater interference fit for the inlet seat, thus ensuring against danger of loosening (and possible falling out) during working conditions.

Until comparatively recently, the valve seat material which has been widely used with considerable success is aluminium bronze. This material has a fairly high expansion, is reasonably resistant to corrosion and wear, and is structurally stable under working conditions. The introduction of fuel containing lead tetra-ethyl, however, imposed conditions of corrosion and scaling which render aluminium bronze unsuitable for certain engine types. The leaded fuel contains bromides, which under combustion conditions produce hydro-bromic acid. This hydro-bromic acid has a detrimental effect on both the valve and the valve seat insert, and both these components have provided serious problems to the designer and metallurgist.

Beryllium bronze is also adversely affected by the products of combustion and leaded fuel. Apart from this difficulty, beryllium bronze with its very high heat conductivity and high hardness would appear to be an excellent alloy for valve seat construction. Latterly a great deal of investigation has been directed to the adaption of high expansion steels for the valve seat component. Considerable success has been achieved with a nickel manganese chrome type of steel, of which a typical analysis is shown in Table III. While this steel has a low heat conductivity, this is more than offset by the very high expansion figure, which approximates closely to that of the aluminium head material. The resistance of this steel to combustion products arising from the use of leaded fuel is very much superior to the aluminium bronze types, and further its surface rapidly work-hardens under the hammering effect of the valve, so that wear is almost negligible. The high expansion figures of the nickel manganese chrome steel also renders it suitable for inlet seats for reasons which have been explained in the earlier portions of this section.

Valves.

The valve, and in particular the exhaust valve, has provided a problem of almost continuous attention and experiment. The exhaust valve has to withstand repeated high impact loading at temperatures which may reach 800°C. Furthermore, at this temperature the material must resist normal atmospheric and exhaust gas corrosion, and in addition the stem portion, by reason of its mechanical operation in the valve guide, must have good bearing characteristics in conjunction with the guide material.

It is not easy to find an alloy which will fulfil all the requirements mentioned above, and it has been found necessary to adopt various metallurgical and mechanical devices to overcome the deficiencies of the materials of best general characteristics.

Table IV gives details of physical properties of the valve steels in most general use.

For resistance to corrosion and scaling, it is found necessary to employ nickel chromium alloy steels of the austenitic class.

These steels also give the highest strength at elevated temperatures, and being austenitic are very stable, structurally, at these temperatures.

Austenitic steels are, however, notoriously bad as bearing materials, and this fact has necessitated investigation into improving the surface condition of the valve stem to work satisfactorily with the valve guide. Attempts have been made to work-harden the stem by forging on a falling heat, but only a comparatively small increase in hardness is obtainable.

A much more satisfactory result is obtained by employing the nitrogen hardening process. A case of approximately 0.004" having a hardness of 800 to 1,000 Brinell may be obtained by this method, and this has given eminently satisfactory results as regards bearing surface. Nitrogen hardening has one serious disadvantage, the high anti-scaling properties of the steel are seriously impaired by it, so that it is necessary to confine the hardening operation strictly to the stem portion (Fig. 3). Although the strength properties of modern valve steels at high temperatures are remarkably good, when compared with the normal

structural steels, modern engine conditions have become so severe that these high figures are now inadequate to meet present demands. It has been found necessary to consider schemes for maintaining valve temperatures at a lower general level, thus taking advantage of the higher strength properties available.

The main principle involved in most of the cooling methods employed has been to endeavour to transmit the heat from the valve head and neck to the stem portion as quickly as possible, the heat received by the stem being transferred to the valve guide, and thence to the head and head cooling fins.

The greatest problem in this method of lowering the valve head temperature arises from the fact that steels, particularly the austenitic steels, have a very low heat conductivity value. This has been overcome in a very ingenious way.

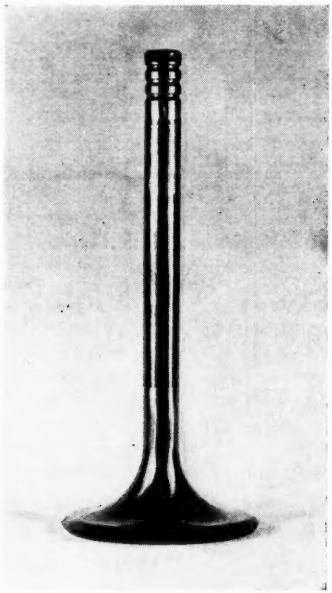


FIG. 3.
Valve with nitrided stem.

The idea is to make the valve hollow and partially fill the space with a substance of low melting point. Various substances have been tried, including low melting point salts, solid sticks of copper, and more latterly metallic sodium. The last named is the most efficient. When using sodium, about $\frac{2}{3}$ of the hollow space is filled with the metal and then it is sealed to prevent leakage. Now sodium has a heat conductivity of 0.4 of that of copper (compared with 0.024 for the valve metal), moreover, its melting point is 95°C. When the valve begins to heat up, the sodium quickly melts, and the oscillation of the valve shoots the molten metal up to the head and back down the stem again at a very fast rate. The sodium collects the heat from the head and transmits it to the stem, thus maintaining the head at a generally lower temperature. Experience has shown, however, that a too effective transfer of heat by this method may produce other difficulties. There may be more heat transferred than the valve guide can possibly carry away, so that the whole valve may be heated up in an alarming manner. In practice the cooling effect of the sodium is regulated so as to give a reasonable

lowering of the head temperature commensurate with satisfactory transference of the heat through the guide.

One further development of valve construction should be mentioned. While the temperature of the valve head has been substantially lowered by sodium cooling, and thereby the tendency to scaling has been reduced, the use of leaded fuels imposes conditions of corrosion and scaling which still cannot be met by the valve materials at our disposal. This applies particularly to the valve seat portion. Scaling and pitting of the seat may produce blowpiping and ultimate burning of the valve, with disastrous results.

This difficulty has been met by coating the seat with a material of very high hardness and resistance to ethyl fuel attack. The material which has given the best results to date is Stellite. This is a cobalt chrome alloy and a typical composition is as follows: C. 1.23 per cent., Cr. 26.73 per cent., Si. 2.70 per cent., W. 4.00 per cent., Co. 65.00 per cent.

The Stellite is attached to the valve by a method similar to welding, and great care is used to produce a coating free from cracks, blowholes, etc. A special feature of Stellite is that its hardness is maintained at temperatures as high as 700°C.

CRANKCASES.

Table V gives the properties of materials which have been used in crankcase construction.

The crankcase is one of the engine components where considerable weight saving can be taken advantage of, since the stresses imposed on it can be safely met with light alloys of aluminium and magnesium.

Early engines invariably used cast alloys, but this method of manufacture involved considerable production difficulties. A high percentage of rejections due to faulty foundry technique, including porosity, blowholes, draws, cracks, trapped skin, etc., was common.

Difficulty was often found in keeping casting section thicknesses uniform, so that a considerable amount of scruffing and polishing was found necessary. Improved foundry methods and better light alloy materials have overcome many of the difficulties mentioned, but a big step forward was made when forgings became available. It should be mentioned that the radial engine crankcase can be so designed as to permit of simple treatment as a forging. On the other hand, the in-line engine crankcase, by reason of design limitation, must of necessity be constructed from castings.

While the early aero engine crankcases were made from aluminium alloys, many attempts have been made to introduce magnesium alloys for this part. Considerable success in this direction has been achieved on certain low-powered engines, but so far the application of these alloys to high-powered engines has not proved so promising.

The magnesium alloys so far developed, while possessing good maximum stress and ductility values, have been inferior to the aluminium alloys as regards proof strength, hardness and creep strength in the region of 100-150°C. Common troubles experienced with magnesium crankcases included loosening of bearing-housings, pasting of joint faces, and loosening of cylinder holding-down studs. These defects are attributable to the deficiencies in the mechanical properties mentioned above.

Magnesium alloy components are also prone to distortion during machining and engine running.

This trouble of relief of internal stress is not, however, confined to the magnesium alloys, both Duralumin and R.R.56 forged materials have exhibited marked signs of internal stress, and in order to relieve this stress, these materials have been used in the annealed or partly annealed condition, giving mechanical properties greatly inferior to the fully heat-treated alloys.

It is extremely unfortunate that full use cannot be made of the high mechanical properties of the modern aluminium alloys, and while some future metallurgical

development may yet enable the heat-treatment of these alloys to be performed without the introduction of these stresses, present indications suggest that the amount of internal stress produced is directly proportional to the tensile strength of the material.

Valve Springs.

No description of troubles associated with aero engines is complete without some reference to valve springs.

This component has a particularly difficult task to fulfil, being subject to high reversed torsion stresses and exposed to temperatures ranging from normal to approximately 250°C.

The problem of the valve spring is intensified by the fact that it is difficult to manufacture wire which is uniform in mechanical and physical properties, and in addition the actual winding of the springs calls for a high degree of technical skill and attention to detail.

Considerable controversy exists regarding the best material to use for aero engine valve springs, and in this country there are those who favour heat-treated chrome-vanadium wire and others who prefer hard drawn carbon steel wire.

Time does not permit of a detailed examination of both materials, and I propose to refer only to hard drawn wire, as it is this material which is used on " Bristol " engines.

Valve springs, as they are at present widely produced, differ from all the other highly stressed parts of an engine in that the original drawn surface is retained without any removal of surface metal. In the case of stampings, forgings and bars for highly stressed steel components, one would not consider for a moment the use of these parts in their " as stamped or forged " condition. This is because there is considerable danger of defects existing on, or near the surface, produced by the forging, heat-treatment or other manufacturing processes.

While great care and attention is taken to eliminate and prevent the occurrence of such defects in the manufacture of valve spring wire, the efforts of the manufacturers have been far from successful in this respect. Some attempts have recently been made to grind the wire in long lengths, but while lengths of approximately 150 feet have been produced in this way, these quantities are not really suitable for quantity production of valve springs.

Among the various types of surface defects found on valve spring wire, the following are common causes of spring failure:—

(1) Decarburisation (varying in depth from a few tenths to three-thousandths of an inch).
(2) Roaks.
(3) Laps.
(4) Longitudinal cracks.
(5) Surface draw marks.

The detection and elimination of wire having the type of defects mentioned above demands an elaborate inspection procedure, covering all stages of the manufacture of the wire and valve spring components (Fig. 4).

Table VI gives some interesting figures showing the effect of surface finish and decarburisation on the fatigue properties of hard drawn carbon spring wire.

Fretting and Warting.

The problem of fretting and warting is one which is always with us in some form or another. In some cases the effects may be quite trivial and relatively unimportant. In others its effect may be far reaching and indeed positively dangerous.

Fretting is caused by very small repeated movements of two metal surfaces in close mechanical contact. The two surfaces appear to tend to weld together

in a manner similar to pressure welding, the difference being, of course, that the average temperatures existing are quite low and not higher than 150°C. Locally, due to friction, the temperature may be considerably higher.

Experience has shown that this tendency to fret is more marked when the mating materials are similar in physical and mechanical properties, and in this sense the fretting problem may be likened to the problem of the selection of materials for good bearing properties. Two interesting examples of engine components subject to fretting conditions are the articulating rod eyes of a radial engine master rod, and the crankshaft maneton joint, also used on certain radial engines.

The importance of the problem in these two instances can be appreciated when it is explained that severe fretting may lead to the formation of a fatigue crack, which ultimately causes fracture of this part.

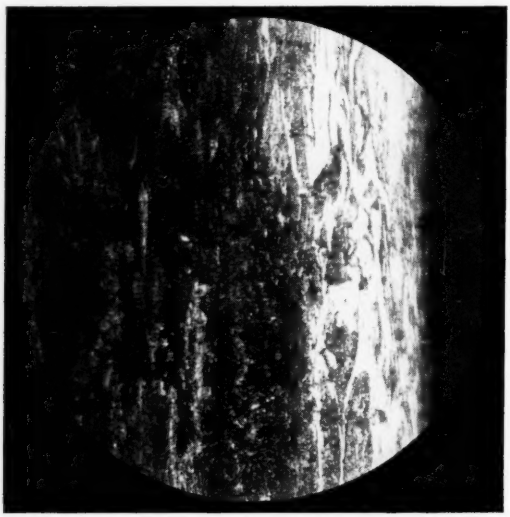


FIG. 4.
Decarburised spring wire.

Many interesting experiments have been carried out employing various schemes for counteracting fretting. One idea is to interpose between the mating surfaces a thin film of material of different physical characteristics from those of the two components.

Chromium plating, tinning (by heat and electro-deposition) and copper plating have been tried with varying degrees of success.

The best methods, however, appear to be those where the hardness values of the surfaces are raised by such processes as case-hardening and nitrogen-hardening.

In conclusion, I would like to repeat the remarks I made in the earlier portions of this paper, namely, that it has been possible to deal with only a few of the multitudinous problems which the modern aero engine offers to the metallurgist. I have selected those which I consider might make an interesting appeal to those who, while being acquainted with the somewhat frequent changes made in the materials of engine construction, may not be fully aware of the fundamental reasons underlying such developments.

TABLE I.

Crankshaft, Connecting Rods, Highly Stressed Studs, Bolts, etc.

MECHANICAL PROPERTIES.

Material.	Specification.	Max. Stress. Tons/sq. in.	Elongation %	Izod. Ft. lbs.	Hardness. Case 1.	Hardness. Core 2.	Endurance Limit. 3. Tons/sq. in.	Use.
Ni. Cr. steel ...	S.11	60.0	24.0	80	—	286	±33.5	Studs, bolts.
Ni. Cr. steel ...	S.11 (K.1)	64.0	22.4	70	—	293	±35.0	Crankshafts.
Ni. Cr. steel ...	S.65	68.0	21.0	60	—	311	±36.0	Conn. rods.
Ni. Cr. steel ...	S.81	70.0	20.0	60	—	321	±36.5	Conn. rods.
Ni. Cr. steel ...	S.82	90.3	15.5	52	—	402	±40.5	Studs.
Ni. Cr. steel ...	B.N.D.	109.5	18.0	31	—	495	±45.25	Conn. rods.
Ni. Cr. steel ...	B.N.D. (cased)	109.5[4]	18.0[4]	31[4]	750	495	±46.0	Conn. rods.
Cr. Mo. steel ...	D.T.D. 228	61.2[4]	25.0[4]	80[4]	650	286	±48.0	Crankshafts.

1 = Vickers Diamond Hardness Numeral. 2 = Brinell Hardness Numeral. 3 = Basis 107 Reversals. 4 = Of Core.

TABLE II.

Pistons, Cylinder Head Alloys for High Temperature Work.

MECHANICAL PROPERTIES.

Material.	Form.	Specification.	20°C. Max. Stress. Tons/sq. in.	20°C. Elong. %	350°C. Max. Stress. Tons/sq. in.	350°C. Elong. %	Uses.
Al.-Cu.	Cast	3.L.11	9.0	3.0	3.0	5.0	Pistons, general castings.
Al.-Ni.-Cu.-Mg. ...	Cast	"Y" alloy	16.0	2.0	5.2	4.0	Pistons.
Al.-Ni.-Cu.-Mg. ...	Forged	"Y" alloy	24.0	16.0	8.9	50.0	Pistons, cylinder heads.
Al.-Ni.-Cu.-Si.-Mg. ...	Forged	R.R.59	28.0	6.0	7.5	45.0	Pistons, cylinder heads.
Al.-Si.-Cu.-Mg. ...	Forged	S.32	22.3	3.0	5.4	—	Pistons.

TABLE III.

Valve Seat Materials.

Material.	ANALYSIS C.	Ni.	Al.	Be.	Zn.	Si.	Mn.	Cr.	Cu.	Brinell Hardness Numeral. 15°C.	400°C.	Co-efficient of Expansion. per °C.	Therm. Conductivity Cal./Cm./Sec/°C.
Aluminium bronze ...	—	1.25	10.0	—	—	—	—	—	R	190	110	0.0000177	0.165
Beryllium bronze ...	—	—	—	2.5	—	—	—	—	R	302	154	0.000017	0.32
Silicon brass (Tungum)	—	1.4	2.25	—	11.4	1.15	—	—	R	179	—	0.000020	—
Ni. Cr. Mn. steel ...	0.54	11.88	—	—	—	0.41	5.15	3.76		160	114	0.0000209	0.024

R = Remainder.

TABLE IV.

Valve Steels.

Material.	ANALYSIS. C.	Si.	Mn.	Ni	Cr.	W.	Co.	Mo.	TENSILE TEST. At 150 °C. Max. Tensile Strength Tons/sq. in.	Elongation %	At 800 °C. Max Tensile Strength Tons/sq. in.	Elongation %	Co-efficient of Expansion per °C.
Five per cent. nickel steel	0.12	0.30	0.40	5.0	0.30	—	—	—	70.0	19.0	4.0	60.0	0.000011
Cobalt-chromium	1.20	0.53	0.24	0.41	12.7	—	3.21	0.70	55.0	13.0	13.0	—	0.000011
Silicon-Chromium ...	0.39	3.30	0.42	0.24	8.6	—	—	—	68.0	20.0	4.87	60.3	0.000011
Firths H.R. Crown-Max	0.44	1.70	0.32	11.4	22.0	3.9	—	—	50.0	27.0	19.0	40.0	0.000017
Hadfields Era A.T.V. ...	0.44	1.84	0.94	28.0	14.5	3.4	—	—	48.0	29.0	16.5	32.0	0.000017
Kayser Ellisons KE.965 ...	0.41	0.92	0.79	14.7	14.0	2.0	—	—	63.0	23.5	17.2	40.0	0.000017

TABLE V.

Crankcase Materials.

Form.	Trade Name.	Quality.	Condition.	Specification.	TENSILE TEST. Tons/sq. in. Limit of Proportionality.	0.1 % Proof Stress.	Max. Stress.	Elongation %	R. of A. %	Brinell.	Endur. Limit Basis 5×10^7 Reversals. Tons/sq. in.
Casting	—	Al. alloy	—	3.L.11	—	—	9.0	3.0	—	55	±4.00
Casting	—	Mg. alloy	Cast	D.T.D.59	—	4.3	10.2	3.0	6.0	60	±3.75
Casting	R.R.50	Al. alloy	H.T.	D.T.D.133.B	—	6.9	11.2	2.5	4.3	65	±4.50
Forging	Duralumin	Al. alloy	H.T.	3.L1	11.0	16.0	28.0	23.0	36.0	121	±9.25
Forging	Duralumin	Al. alloy	A.	—	4.8	7.0	16.7	17.7	33.6	68	±6.5
Forging	R.R.56	Al. alloy	H.T.	D.T.D.130	10.2	19.9	27.6	11.0	20.8	134	±10.5
Forging	R.R.56	Al. alloy	N.A.	—	5.4	11.2	19.8	16.0	36.0	88	±8.0

H.T. = Heat-Treated. N.A. = Normalised-Annealed. A. = Annealed.

TABLE VI.

Effect of Surface Finish and Decarburisation on the Fatigue Strength of Hard-Drawn Carbon Valve Spring Wire.

Condition.	Reduction. %	Max. Tensile Strength. Tons/sq. in.	Endurance Limit. Tons/sq. in.	Factor: End. Limit/Max. Tensile Stress.
Drawn from decarburised rod	75.0	126.1	±23.4	0.185
Drawn from decarburised rod and machine polished	75.0	125.1	±28.3	0.225
Drawn from decarburised rod and polished to 000 emery ...	75.0	124.8	±29.2	0.234
Drawn from rod free from decarburisation	72.5	130.0	±31.7	0.244
Drawn from rod free from decarburisation and machine polished	72.5	127.8	±36.6	0.286
Drawn from rod free from decarburisation and polished to 000 emery	72.5	128.7	±39.4	0.306

ABSTRACTS OF PATENT SPECIFICATIONS.

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

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Aerodynamics.

443,903. *Improvements in or relating to the Streamline Formations of Bodies for Land Vehicles, particularly Motor Vehicles.* Communicated by Tatra Works, Ltd., 200, Kartouzska Smichov, Prague, Czecho-Slovakia. Dated September 5th, 1934. No. 25,576.

It is proposed to collect air from the lower part of the front of a motor car body where it is stated to be dammed up, and to pass it by means of ducts to the rear of the body where it is delivered at the points of incipient air disturbance.

Aeroplanes—Construction.

442,252. *Improvements in or relating to the Construction of Aircraft Wings.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Youngman, R. T., Walcot, Church Crookham, Aldershot, Hants. Dated December 14th, 1934. No. 35,935.

In this wing it is proposed to use a system of girders running down the span of the wing so in end view the girders are arranged similarly to warren bracing. The booms are in the form of a T section and the girders are braced by perpendicular and diagonal members. A covering consisting of two plates separated by a corrugated plate, all three being riveted together, may be used.

442,253. *An Improved Method of Covering Aircraft Components.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Pearce, H. L., of 103, Studland Road, Hanwell, London, W.7. Dated January 18th, 1935. No. 1,745.

The wing has a covering of corrugated metal, the corrugations running longitudinally. Out of some of the crests tongues or loops are pressed out, these being longitudinally directed and arranged in a series which runs in a fore and aft direction. A plain sheet of metal, slotted to give passage to the tongues or loops, is disposed over the corrugated sheet metal; textile fabric is stretched over the component and treated with dope. The fabric is cut to give passage to the

tongues or loops and flax cords, tapes, or the like, are bound round the component so as to pass beneath the tongues or loops, tied and covered with frayed edge fabric applied by means of dope.

444,609. *Improvements in or relating to Aircraft.* Bleriot Aeronautique, 167, Quai Gallieni, Surasnes (Seine), France. Convention date (Belgium), October 5th, 1934.

The aeroplane described is a monoplane having two fuselages carrying the tail, etc., and having a centre nacelle with two motors in tandem. Each of the fuselages is watertight so as to permit the machine to alight on water and each fuselage also contains a landing chassis, shown as consisting of a number of wheels arranged in line. When it is desired to rise from water a detachable cover, carried in the aeroplane, is fitted to the bottom of the aeroplane so as to cover the wheels; the rear part of this appliance is formed as a step. This cover may be dropped in flight.

443,005. *Improvements in or relating to Aircraft.* Ueskomoravska-Kolben-Daner Co., Ltd., 36, Palackero, Prague X, Czecho-Slovakia, and Slechta, 399, Obvada, Prague IX, Czecho-Slovakia. Convention date (Czecho-Slovakia), September 22nd, 1934.

The aeroplane proposed is a high wing cantilever monoplane of normal type having the two occupants seated side by side approximately below the foremost third of the wing, which latter is mounted on the top of the fuselage. In order to permit easy entrance and exit to or from the seats the leading portion of the centre section of the wing is adapted to be folded back.

445,437. *Improvement in or relating to Aircraft Structures.* The Bristol Aeroplane Co., Ltd., and Russell, A. E., both of Filton House, Bristol. Dated December 5th, 1934. No. 34,987.

It is proposed to use a wing spar in an aeroplane wing placed in the position of maximum depth of the wing, and strong enough to resist all the bending moments on the wing. At each side of this spar and at some distance from it are placed two vertical walls, these and the spar being connected by a rigid metal skin, hence providing for torsional bracing. In order that the vertical walls may not take bending moment they are attached to the fuselage by a single horizontal hinge.

AEROPLANES—GENERAL.

445,829. *Improvement in or relating to Means for Launching Aircraft.* Mayo, R. H., 55, Pall Mall, London, S.W.1. Dated December 20th, 1934.

In the case of aircraft consisting of two components arranged to separate in flight, it is stated that it may be desirable for various reasons to prevent separation taking place until the machine has reached a predetermined height. It is proposed, therefore, to provide an over-riding lock, operated by a capsule of the type used in barometers, so that this lock is released only at the desired height permitting separation to be effected.

AIRSCREWS.

441,763. *Improvements in Airscrew Drives.* Tresilian, S. S., Tresidder, Burley Lane, Quarndon, Derby, England; Rubbra, A. A., Red Roofs, Carlton Road, Derby, England; and Gass, E. A., Norimar, Melbourne Road, Chellaston, Derby, England. Dated July 20th, 1934. No. 21,304.

This specification describes a drive claimed to be particularly suitable for cases where the propeller is to be mounted some distance in front of or behind the

engine. There is an extension piece supporting the propeller shaft in roller bearings immediately behind the propeller hub, while the shaft is driven by a gear wheel which is internally toothed fitting to a gear wheel externally toothed, the latter driving the propeller shaft. The arrangement is stated to give necessary flexibility.

443,566. *Improvement in Airscrews.* Johnson, K. C., Asiatic Petroleum Co., Ltd., St. Helen's Court, Great St. Helen's, London, E.C.3. Dated August 1st, 1934. No. 22,420.

It is proposed to construct airscrews so that they have a large angle of incidence near the tips of the blades, and, in order to enable this to be done without stalling the tips each blade is provided with an auxiliary aerofoil extending along the blade and situated a short distance from the blade on the suction side, the position being above the point of maximum thickness of the blade.

AIRSHIPS.

443,554. *Dirigible Airships or Balloons.* Juan Montilla y Cabellos de Oropesa, Calle San Bernardo No. 113, Madrid, Spain. Dated May 29th, 1934. No. 16,024. Specification not accepted.

It is proposed to propel the aircraft by means of a propeller actuated by a number of wind screws driven by the air current.

446,563. *Improvements in Airships.* Goetz, A., 6, Eppendorferstieg, Hamburg 39, Germany. Convention date (Germany), September 10th, 1934.

The airship proposed has an upper half of approximately elliptical section and a lower half of approximately circular section, the upper half projecting beyond the lower. In the upper half are arranged channels for air and it is claimed that the construction increases the safety of airships in flight and minimises the effect of gusts which would normally disturb the flight.

ARMAMENTS.

444,991. *Means for Mounting in an Aircraft the Motor to which a Gun Barrel is Secured.* Knoller, E., Liebenberstrasse 7, Vienna 1, Austria. Convention date (Germany), May 8th, 1934.

In the case of a gun combined with an aircraft motor and firing through the propeller shaft of the motor, or otherwise, it is proposed to attach a recoil-absorbing mechanism between the motor and the aeroplane so as to take advantage of the mass of the motor in absorbing the recoil. In some cases it may also be advisable to mount a recoil-absorbing mechanism between the gun and the motor.

443,997. *Improvements in or connected with Aerial Trailers and the Like.* Irving Air Chute of Great Britain, Ltd., Icknield Way, Letchworth, Hertfordshire. Dated July 15th, 1935. No. 20,201.

This specification describes an apparatus which may be towed by an aircraft so as to provide a target for gunnery practice or for any other desired purpose. It consists of an approximately cylindrical body, the front end of which consists of a bridle arranged to make connection with the tow rope. This bridle has fabric arranged between the ropes so as to form a number of fins which direct the air into the next portion which consists of a number of sleeves, arranged in the circumference of a circle. This is followed by a plain cylindrical portion. The whole construction is carried out in flexible materials so that it can be folded when not in use, and the design is stated to render the apparatus stable in flight and to ensure inflation.

442,973. *Improvements in Apparatus for Dropping Armed Vehicles and other Articles from Aircraft.* Elia, G. E. (Count), 9, Via S. Valentino, Rome, Italy. Convention date (Italy), February 26th, 1934.

The parachute used for this purpose carries two containers, one containing the car and the other the crew. The container carrying the car touches the ground first, reducing the vertical velocity of the parachute and reducing the landing shock of the container carrying the crew. The containers may be so arranged that they can safely float on water and shock-absorbing means are described to reduce landing shock.

446,295. *Improvements in Gun Arrangements for Aircraft.* Smolik, A., Prague, Litnany, Czecho-Slovakia. Dated November 1st, 1934. No. 31,381.

The arrangement described shows an aircraft with guns mounted in the fuselage and the wings. These guns are arranged so that the farther they are away from the centre line of the aircraft, the farther distance in front of the aeroplane does their line of fire intersect. The pilot may rotate them horizontally during firing so as to make their lines of fire parallel or divergent.

446,134. *An Improved Adjustable Hood for Aircraft and the Like.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex; Lobelle, M. J. O., Ludlow, 298, Langley Road, Langley, Bucks; Ordidge, F. H., Soircroft, Croft Gardens, Ruislip, Middlesex; and Holroyd, F., Old Hatch Manor, Ruislip, Middlesex. Dated April 23rd, 1935. No. 12,246.

The proposed aircraft hood consists of a rigid structure covered with panels of a transparent material, some of which may be slidable to permit ingress and egress. It is carried by four legs projecting downwards into the fuselage, which are mounted so as to permit the whole hood to be raised or lowered. This movement is controlled by a rack or pinion gear or any convenient method operated by the pilot. The hood is also provided with a flap hinged on a horizontal axis which may be armoured.

CONTROL OF AIRCRAFT.

445,771. *Improvements in or relating to Vertically Displaceable Rudders for Aircraft.* Teisseyres ul Sandomierska 7, Warsaw, Poland, and Zdaniewski, Biala Podlaska, Poland. Dated October 9th, 1934. No. 28,927.

In order to assist control of an aircraft during a spin and also to keep a clear field of fire for a gun firing above an aeroplane fuselage, it is proposed to arrange that the fin and rudder of an aeroplane, which normally project above the fuselage may, at the will of the pilot, be slid downwards so as to project below the fuselage, leaving the top clear.

443,651. *Improvements relating to Wing Flaps for Aircraft.* Miles, F. G., and Powis, C. O., of Reading Aerodrome, Woodley, Reading, Berks. Dated September 27th, 1934, No. 21,745/34, and October 31st, 1934, No. 31,250.

This specification refers to flaps of the Shrenck type and is concerned mainly with such flaps mounted on a low wing monoplane. The flap is in sections, portions being fitted to the taper part of the wings, portions to the parallel section wing root, and a further section underneath the fuselage, the whole flap extending from aileron to aileron. The portion of the flap fitted under the fuselage works the reverse way to the others and hence acts as a servo-motor. There is also provision for wing folding inasmuch as a coupling device is fitted consisting of a spindle having a diametrical slot mating with another, the end of which is bulbous in section. These are registered when the flap sections are all up or all down, so that the hinged parts may be raised so as to enable the wings to be folded backwards.

442,122. *Improvements in or relating to Supporting Surfaces for Aircraft.* Letov Vojenska Tovarno Na Letadla, Letnany No. 65, Prague, Czecho-Slovakia, and Pekarak, Z., Letnany No. 60, Prague, Czecho-Slovakia. Dated April 26th, 1934. No. 12,663.

In order to obviate excessive air forces on high speed aircraft in flight, it is proposed to provide the wings with flaps which can be opened, and which, when opened, spoil the aerodynamical properties of the wing. These flaps are opened automatically, preferably by an electrical device which is controlled by a small surface which moves against a spring when the aerodynamical forces become critical, thereby making electrical contact and actuating the flaps.

442,027. *Improvements in Servo-Motors for Use on Vehicles.* A communication from Societè des Appareils d'Aviation Marcel Gianoli, 7, Rue d'Artois, Paris. Dated July 30th, 1934. No. 2,226.

The servo-motor proposed consists of a surface which may be set at an angle to the fluid flow in which a tunnel is provided so as to ensure that the direction of the fluid flow is fixed. The surface is mounted on a frame which, by pivoting, actuates the driven member, the pivoting being produced by the forces on the surface caused by this latter being set at an angle to the fluid flow. The tunnel may be orientated.

443,516. *Improvements in or connected with Wings for Aircraft.* Short Bros., Ltd., and Gouge, A., both of Seaplane Works, Rochester, Kent. Dated January 7th, 1935. No. 488.

The apparatus described is a form of flap for increasing the lift of the wing. It consists of a surface, the upper portion of which is an arc of a circle which is normally fitted in a recess at the rear of the wing, and in this position does not interfere with the normal camber. When operated, it moves backwards in a path curved to the radius of its upper surface. If used over the full span of the wing the outer sections can be used as ailerons by means of differential control.

444,715. *Improvements in or relating to Apparatus for Automatically Stabilising the Speed of Aircraft.* Siemens Apparate und Maschinen Gesellschaft mit Beschronkter Haftung, Askanischer Platz 4, Berlin, S.W.11, Germany. Convention date (Germany), March 7th, 1934.

It is proposed to stabilise the air speed of aircraft with relation to the ground speed by means of a velocity meter. This apparatus consists of a frame on which is mounted two gyroscopes running in opposite directions and so coupled together by toothed segments that they are constrained to undergo equal and opposite deflections. The precessional axes in the frame lie parallel to the direction of flight while the axes of rotation are vertical. On one precessional axis there is a rotary magnet with an energisation proportional to the directional force acting on the gyroscopes due to the earth's rotation. The apparatus is arranged to act as a gyroscopic pendulum having a period of oscillation corresponding to that of a pendulum of the length of the earth's radius or 84 minutes approximately. Hence the pendulum always maintains a vertical situation independent of horizontal acceleration and the gyroscopes will indicate by their precessional movement the land speed of the craft.

Methods of application of this device are described for the purpose of stabilising speeds.

443,178. *Servo Devices for Use in the Control of Watercraft or Aircraft.* Sir W. G. Armstrong Whitworth Aircraft, Ltd., Lloyd, J., Murray, C. V., and Batchell, J. W., all of Whitley, Coventry, Warwickshire. Dated February 8th, 1935. No. 4,089.

This specification describes a method of operating a servo flap connected to a control element such as an elevator or aileron. The flap is controlled by a lever, connected to a rod which in its turn is connected to a member sliding within

the control member in a fore and aft direction. The movement of this latter member relative to the movement of the control member is regulated by a slot in a plate attached to the main plane in the case of an aileron. This slot is shaped to act as a cam, and by regulating the shape of the slot the precise angle of the servo flap with reference to the angle of the control member can be regulated as desired.

445,270. *Improvements relating to Controls, Air Brakes and the Like, for Aeroplanes.* Ayres, W. H., 5, Abbey Road, London, N.W.8, and Tiltman, A. H., The Air Port, Portsmouth, Hants. Dated September 4th, 1934. No. 25,493.

The control referred to is an aileron, though it is stated that a similar arrangement may be used for other controls. The aileron described is hinged to the wing at its upper surface and the large gap thus caused on the underside is covered by a spring flap. This flap is made large enough to act as a split flap and is fitted with controls so that it can be used in this way.

445,992. *Improvements in Aircraft with Transversely Hinged Wings.* Jacquemin, A. F., Sancourt par Doulaincourt (Hte. Marne), France. Convention date (France), September 20th, 1934.

In the proposed aircraft the pilot is provided with a control stick which operates normal elevators in the normal way, but lateral movement of this stick controls the machine laterally by altering the incidence differentially of the wings on either side of the fuselage, the wings being transversely hinged to permit this. In addition, there is a further control which alters the incidence of the wings as a whole, so that the incidence may, for example, be increased for landing, and a spring is provided so that the wing incidence may be automatically returned to normal.

446,094. *Improvements relating to Aeroplane Wings.* Messerschmitt, W., Hannstetterstrasse 118a, Augsburg, Germany. Convention date (Germany), April 14th, 1934.

In order to prevent sudden stalling of the tip of an aeroplane wing, it is proposed to design the wing in such a way that the radius of the leading edge towards the tip is greater than the radius towards the middle of the wing. In addition the leading edge of the middle portion of the wing may be provided with a small angular projection attached to the stagnation point, which, it is claimed, provides the wing with the characteristics of a wing having a sharp leading edge. It is claimed that such a wing is reluctant to drop a wing tip and go into a spin.

ENGINES.

441,823. *Improvements in Mounting and Cooling Engines for Aircraft.* Renault, L., 8, Avenue Emile, Zola, Billancourt (Seine), France. Convention date (France), December 12th, 1934.

The arrangement of cooling proposed is suitable for an air-cooled radial engine mounted horizontally instead of (as usual) vertically in which the propeller is driven by a bevel gear. The engine is mounted so that it is partially buried in the plane and air is admitted by a scoop placed behind the propeller, passes upwards through the cylinders, and escapes through an opening behind the leading edge of the plane and on its upper surface.

446,702. *Improvements in or relating to Aircraft having Air-Cooled Internal Combustion Engines.* The Bristol Aeroplane Co., Ltd., Fedden, H. R., and Butler, L. F. G., all of Filton House, Bristol. Dated March 9th, 1935. No. 7,439.

The invention is described with reference to a radial air-cooled engine, though it is stated that it is suitable for use with other forms of cowled engines. The

cowl proposed for the radial engine is generally of normal form and has an exhaust ring formed into the leading edge of the cowl. It is stated that in such cowls as normally used the air discharged from the annular opening between the cowl and the body is in a state of turbulence causing an increase of the body drag. In order to obviate this it is proposed to arrange a number of circular rings of light sheet metal within the rear of the cowling, and also a number of curved vanes which give the issuing air a whirl corresponding to the whirl produced by the propeller.

446,371. *Improvements in and relating to Radiators for the Cooling Systems of Internal Combustion Engines, Particularly for Aircraft.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Forsyth, A. G., Venlaw, Burden Lane, Cheam, Surrey. Dated May 29th, 1935. No. 15,649.

The radiator described is intended for use below the fuselage of an aeroplane, and has tubes of approximately the same length from back to front, but the tubes are displaced longitudinally to each other so that the whole radiator is convex forward and concave in the rear. A streamline body projects into the rear concavity. This method may be carried out in the vertical plane as well as in the horizontal, or in both planes simultaneously.

KITES.

443,857. *Improvements in or relating to Kites.* Bias Bindings Co., Ltd., Gorgie Road, Edinburgh, Midlothian, Scotland, and Turner, J., of the same address. Dated November 30th, 1934. No. 34,376.

This specification refers to a kite, particularly of the type referred to in specification No. 422,970, and describes a means of providing an adjustable bridle actuated by a cord additional to the towing cord so that the kite may be made to rise or fall. A similar means may be used to divert the kite sideways.

MISCELLANEOUS.

446,983. *Ice Accretion Indicator for Aircraft and Internal Combustion Engines.* Swan, A., Griffith, A. A., and Helmore, W., Royal Aircraft Establishment, South Farnborough, Hants. Dated December 21st, 1934. No. 36,608.

The apparatus proposed consists of a casing carrying on its forward portion a member containing two tubes facing forward with their leading ends cut off at an angle. In one case the tube is open, in the other the leading end is blocked but pierced with a small hole. It is this hole which, when blocked with ice, gives the indication. These tubes are connected one to each side of a flexible diaphragm, the passages connecting them being provided with bleed holes. It would follow, therefore, that when the hole referred to was blocked with ice the pressures on each side of the diaphram would no longer be equal. Hence the diaphram would move to one side and it is then arranged to make an electrical contact whence indication of the presence of ice is given in the cockpit of the aeroplane. Heating and other auxiliary devices are described.

MODEL AIRCRAFT.

445,826. *Improvements in Toy Aeroplanes.* Bochme, G., 39, Humboldstrasse, Ludenschied, Germany. Dated November 20th, 1935. No. 32,154.

It is proposed to construct a toy aeroplane of metal and to arrange that all parts shall be elastically mounted so as to prevent damage when landing. The wings, for instance, may have resilient and bendable supporting struts and the tail unit may be mounted on springs attached to the fuselage.

443,373. *A Toy Kite Aeroplane.* Dunn, F. H., Grovelands Munbury, Axminster, Devon. Dated August 24th, 1934. No. 24,387.

This apparatus is a kite roughly resembling an ordinary tractor biplane. The body has a large opening in the front and smaller apertures in the rear so that air can enter. There is a stabilising arrangement consisting of two fins which are connected to the rudder and elevators, and there is a free-running propeller in front.

PARACHUTES.

443,872. *Improvements in or relating to Parachute Packs.* Irving Air Chute of Great Britain, Ltd., Icknield Way, Letchworth, Hertfordshire. Convention date (U.S.A.), April 8th, 1935.

It is proposed to provide a parachute pack in which manually and automatically actuated controls are provided for effecting release of the fastening means associated with the pack, such fastening means being connected or adapted to be connected to a member slidably mounted with respect to a housing or support disposed on said pack. The manually and automatically actuated controls are also connected or adapted to be connected to the slidable member; characterised in that said slidable member is grooved or channelled for receiving the automatically actuating control in such a manner that, in co-operation with the housing or support, such control is maintained in firm connection with the slidable member when the latter is in a position corresponding to the engaged position of the fastening means, but is permitted to become freed as soon as the slidable member is withdrawn into a position, causing release of the fastening means.

444,808. *A Release Device for Parachute Packs.* Rezler, J., 25, Tusarova, Prague VII, Czecho-Slovakia. Convention date (Czecho-Slovakia), December 11th, 1934.

A stud is mounted on a flap of the pack which engages eyelets on other flaps of the pack, the stud being provided with an aperture to take a securing pin. The case is provided with a cap capable of sliding in a telescopic manner, the two being normally pushed apart by a spring. Hence when the pin is removed the flaps are at once disengaged. The pin may be mounted on a swivel to facilitate disengagement.

ROTOR CRAFT.

443,764. *Improvements in Aircraft Sustaining Rotors.* The Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2. Convention date (U.S.A.), August 18th, 1934.

This specification describes a modified rotor for autogiros which is intended to eliminate bouncing, and also to possess other advantages, such as an improvement in aerodynamical efficiency of about 25 per cent. The blades of the proposed rotor are paddle shaped in plan, the broadened end portion of which is the active portion and it is connected to the hub by a streamlined arm. In addition to the hub hinge another is provided between the arm and the blade itself, and additional hinges may be used.

444,395. *Improvements in and relating to Aircraft Sustaining Rotors.* The Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2; Hodgess, F. L., and Bennett, J. A., Holm Foundry, Cathcart, Glasgow. Dated September 17th, 1934. No. 26,662.

This specification relates to rotors having an even number of blades, each pair of oppositely disposed blades being mounted upon a common flapping centre. A

flapping pivot assembly, common to a pair of oppositely disposed blades, includes a blade interconnecting member rotatable with respect to the hub and constituting a load transmitting connection between the root members of the opposite blades. This blade interconnecting member may take the form of a pin or bush freely rotatable on a bearing member (brass or journal) fixed relatively to the hub, and it may either be floating, both the blade root members being rotatably mounted thereon, or it may be fixed to or integral with one of the blade root members, the root member of the other blade being rotatable thereon so as to allow independent flapping. The blade interconnecting member receives the loads transmitted by both the oppositely disposed blades and the opposed centrifugal loads neutralise one another in the blade interconnecting member which transmits only the unbalanced loads to the member of the pivot assembly which is fixed relatively to the rotor hub, so that substantially only the lift loads can give rise to friction transmitted to the hub at the flapping pivots.

444,485. *Improvements in Aircraft Sustaining Rotors.* The Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2, and Bennett, J. A. J., Genista, Newton Mearns, Renfrewshire, Scotland. Dated September 17th, 1934. No. 26,708.

This specification is concerned with autogiro rotors of the type in which the blades are articulated in two planes, one referred to as the lift axis and the other as the drag axis, the two being substantially at right angles to each other, and it describes an improved method of damping the oscillations on the drag axis which has previously been done frictionally. According to this invention the pivot is so arranged that a drag oscillation of the blade has necessarily associated therewith an oscillatory movement of the blade in the flapping plane, whose amplitude is of the same order as that of the drag oscillation.

442,426. *Improvements in and relating to Aircraft with a Rotating Wing System.* Wilkening, F. W. Arlington, of Braeburne Roads, Penn Valley, Montgomery, Pennsylvania, U.S.A. Convention date (U.S.A.), September 20th, 1933.

The aircraft proposed is to be supported by a rotor whose pitch is variable and which may be tilted relative to the fuselage. The rotor is power-driven through a free wheel so as to be capable of autorotation. There are also one or more aerofoil surfaces substantially parallel to the rotor axis and also with the direction of flight. These are cambered so as to produce a torque on the fuselage opposite in direction to that produced by the rotor when power-driven. Means are provided for varying the effective camber of the surfaces which may be fitted with flaps.

444,095. *Gyroplane Apparatus adapted for Road Travel.* Thâon, A., 20, Boulevard Jules Peltier, Saint Cloud, Seine et Oise, France. Convention dates (Luxembourg), June 25th, 1934, and June 17th, 1935.

This apparatus is a combined aircraft and road vehicle, the aircraft being of the autogiro type. It has a motor in front which can be connected with the propeller and a rear drive is taken from the motor through a gearbox to drive the single rear wheel when the appliance is on the road. There are two front wheels which can be steered for road work and which can be extended for use as a landing chassis when the appliance is used as an aircraft. The rotor has blades which can be shortened and the pylon carrier can be folded on to the top of the vehicle. Arrangements are described by which the various movements must be carried out in the proper order and to ensure that the propeller is stopped in the proper position, the controls are changed from road to air, etc.

442,016. *Improvements relating to Aircraft.* Kay Gyroplanes, Ltd., Kay, D., and Dyer, J. W., all of 18, Atholl Crescent, Edinburgh, Scotland. Dated July 27th, 1934. No. 22,022.

This specification describes a method of mounting the rotors of aircraft of the autogiro type so that the rotor supporting member is capable of tilting laterally and in a fore and aft direction by being mounted for such movements upon a single turnable member integral with or mounted upon an axle or equivalent, the arrangement being such that the axis about which lateral tilting takes place and the axis about which tilting in the fore and aft direction takes place both intersect the angle of rotation of the axle or equivalent.

442,137. *Improvements relating to Aircraft.* Kay Gyroplanes, Ltd., Kay, D., and Dyer, J. W., all of 18, Atholl Crescent, Edinburgh, Scotland. Dated July 27th, 1934. No. 22,018.

This specification relates to the type of aircraft fitted with a rotor and is intended to provide means by which automatic compensation is obtained for maintaining the trim of the machine when the rotor is tilted laterally. A rotor supporting member is provided which can be tilted laterally and also longitudinally of the aircraft in combination with means for causing a simultaneous fore-and-aft movement of the said supporting member to take place when the means upon which the latter is carried is operated to tilt the rotor supporting member laterally.

444,572. *Improvements in and relating to Aircraft with a Rotating Wing System.* Wilkening, F. W., Arlington and Braeburne Roads, Penn Valley, Montgomery, Pennsylvania, U.S.A. Convention date (U.S.A.), September 20th, 1933.

The proposed aircraft is approximately of the autogiro type and is arranged so that both the lifting rotor and the propeller can be driven from the engine. Anti-torque surfaces, consisting of laterally extending surfaces similar to fixed wings which may be placed in either of two positions, one approximately horizontal and one approximately upright, so as to be affected by the slipstream of either the propeller or the rotor. The pitch of the rotor blades is alterable at the will of the pilot, as is the pitch of the propeller, and there is a clutch between the engine and the propeller and a free wheel device between the engine and the rotor. By varying the setting of these pitch angles and operating the clutch the engine power may be divided between the lifting and propelling members in any proportion desired.

441,946. *Aircraft Controls.* Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, N.W.1, and Goodyear, E. F., of the Company's Works, Foleshill, Coventry, and Wright, J., and Trevaskis, H., both of the Company's Works, Fort Dunlop, Erdington, Birmingham. Dated October 4th, 1934. No. 28,400.

This method of control applies mainly to giroplanes defined as a type of aircraft possessing a wind-driven rotor on engine-driven propeller to the engine, which is connected to the rotor through a clutch and brakes operating on the rotor and on the landing wheels. The clutch and the two brakes are operated hydraulically, the hydraulic controls being placed on the segment of a circle so that by the movement of a lever they are all operated in the desired sequence, either when being put on or taken off.

446,509. *Improvements in or relating to Aircraft.* Pemberton Billing, N., Royal Court Chambers, Sloane Square, London, S.W.1. Dated October 25th, 1934, No. 30,670, and November 27th, 1934, No. 34,102.

The proposed aircraft is fitted with two rotating wings situated on each side of the machine and rotating in opposite directions. The arms of these rotors

are each hinged at the root in two places, the movement permitted being limited by flat springs. Each arm carries at its extremity a small vertical streamlined plane the incidence of which can be varied during rotation in an appropriate manner so that when the rotors are rotated by the engine the machine may be propelled either forwards or backwards by appropriate incidence variation of the streamline planes. Provision is made to alter the incidence of the rotor blades, and the position of the engine may be varied by the pilot in order to adjust the centre of gravity.

442,015. *Improvements relating to Aircraft.* Kay Gyroplanes, Ltd., Kay, D., and Dyer, J. W., all of 18, Atholl Crescent, Edinburgh, Scotland. Dated July 27th, 1934. No. 22,021.

In the case of rotating wing aircraft, in which the rotor is initially spun up by the motor, it is proposed to arrange that when the machine is on the ground the rotor blades are at a zero or negative angle of incidence and to cause the machine to rise by increasing this incidence. The mechanism proposed includes a control member within the rotor hub which actuates levers which in turn actuate a spindle carrying the rotor blade, this spindle being displaced angularly forming a type of Z crank. Springs are used which tend to hold the blades at positive angles, and there is an automatic arrangement for disengaging the clutch.

UNDERCARRIAGES.

443,616. *Aircraft Brake Controls.* Dunlop Rubber Co., Ltd., 32, Osnaburgh Street, London, N.W.1; Goodyear, of the Company's Works, Foleshill, Coventry; Wright, J., and Trevaskis, H., of the Company's Works, Fort Dunlop, Erdington, Birmingham. Dated December 6th, 1934. No. 35,027.

Reference is made to the prior specification 397,897 in which the application of the brakes is effected by a connection to the rudder bar. It is stated, however, that in large aeroplanes the size of the rudder is apt to result in the forces transmitted to the pilot being greater than he can control and in consequence there may result an involuntary misapplication of the brakes. It is proposed, therefore, to control the brakes independently of the rudder and bar by manual means such that equalised or differential application of the brakes may be effected with ease, whatever the size of the aircraft. According to this invention aircraft brake controls, of the kind having a plurality of fluid pressure relays positioned for actuation by a common actuating link displaceable symmetrically or asymmetrically in relation to the axes of the relays, are characterised in that the displacement of the said link is controlled by a plurality of operative connections to means displaceable in two directions at right angles to one another.

442,133. *Improvements in or relating to Aircraft Undercarriages.* Dowty, G. H., 17, Lansdowne Crescent, Cheltenham, Gloucester. Dated July 2nd, 1934. No. 19,457.

The appliance described consists of a strut designed to break about its centre and intended to form part of a retractable chassis for aircraft. The strut preferably contains two double acting hydraulic jacks, one in each half of the struts. The piston rods of these jacks each carry a fixed gear wheel, each of which gear into two other gear wheels which gear into each other. The gears are carried by a triangular frame and the effect of introducing fluid pressure into the jack is to cause the strut to break or to recover according to the side of the jack pistons to which the fluid is admitted.

445,202. *Aircraft Controls.* Dunlop Rubber Co., Ltd., Osnaburg Street, London, N.W.1, Goodyear, E. F., of the Company's Works, Foleshill, Coventry, Wright, J., and Trevaskis, H., of the Company's Works, Fort Dunlop, Erdington, Birmingham. Dated October 4th, 1934, No. 28,399, and April 13th, 1935, No. 11,488.

The wheel brakes described are intended for use with aircraft of the autogiro type and are arranged so that, when starting, the wheel brakes are released simultaneously with the rotor clutch, and also come into action with the latter when preparing to start. There are a number of valves controlling fluid pressure collectively or selectively operated and which, when actuated in the first instance before flight, bring the aircraft into readiness for flight by applying the wheel brakes and engaging the rotor clutch, and when actuated in the second instance for taking off release the wheel brakes and prevent the re-engagement of the rotor clutch.

REVIEWS.

AIRDAYS.

By John F. Leeming. Published by George G. Harrap and Co., Ltd. Price 7/6.

Mr. Leeming is well known in aviation circles for his work in connection with the Lancashire Aero Club, and is a member of the Racing Committee of the Royal Aero Club. He seems to have started to take an interest in aviation in the year 1922 when he built a glider.

This book contains a description of his subsequent adventures, of his meetings with many aeronautical notabilities, of the founding of the Lancashire Aero Club, and of many other matters, told with the skill of an experienced writer who is possessed with a keen sense of humour.

The result is a book which is extremely entertaining, and which is, at the same time, a history of certain events which deserve to be remembered not only for their place in the history of aviation in general, but also for an illustration of the way in which difficulties vanish before a man who knows what he wants and is determined to get it.

FROM BOX-KITES TO BOMBERS.

By George Fyfe. Published by John Long, Ltd. Price 16/-.

This book may be described as an outline of the history of aviation. It has been written by an experienced journalist who knows his subject and has the journalistic instinct for the event which will appeal to the imagination of the public and who knows how to enhance the appeal by the method of description.

The book adds nothing to our knowledge of aviation history, but it may fulfil a useful purpose by being read by the public who, it is to be hoped, will consequently be led to take a more knowledgeable interest in aviation matters. Mr. Fyfe naturally and properly stresses the British share in the development of the aeroplane, and many of his readers will learn for the first time the importance of the British contribution. Many know all about the Atlantic flight of Colonel Lindberg, but few remember the more notable flight of Alcock and Brown in 1919, when they crossed the Atlantic in an unsuitable machine, under appalling weather conditions, and without the navigational instruments which simplified the task for their successors.

The 605th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS.

A meeting of the Society was held in the Lecture Theatre of the Institution of Electrical Engineers, at Savoy Place, Victoria Embankment, London, W.C.2, on Monday, March 23rd, 1936, for the reading and discussion of a paper on "The Jointing of Materials by Welding," by Mr. R. H. Dobson and Mr. R. F. Taylor, which was read by Mr. Taylor. In the chair, Lieut.-Colonel J. T. C. Moore-Brabazon.

The PRESIDENT: Mr. Taylor was in the first place apprenticed with Messrs. A. V. Roe and Co., Ltd., and at the same time had studied at the Manchester School of Technology. Later he had made a special study of metallurgy and allied subjects. In the works of Messrs. A. V. Roe and Company he had held various posts, from foreman to chief inspector, and had since been in charge of all experimental and research work there. In that connection the company had carried out intensive research into different forms of welding, resulting in the building of the "Tutor" and other welded fuselage machines. The company had since developed electric automatic spot welding and seam welding of spars, and in all those experiments and researches Mr. Taylor had played the most prominent part.

THE JOINTING OF MATERIALS BY WELDING

By R. H. DOBSON and R. F. TAYLOR.

This is a subject which during recent years has aroused considerable interest in all industries and particularly in the aircraft industry and a large amount of investigation work has been carried out. In some industries, both light and heavy, the growth of welding as a "production tool" has been phenomenal, and the same growth is at the present time occurring in the structural steel work and shipbuilding industries. If one views this change which is taking place it will be observed that the change is entirely at the expense of riveting and bolting, and before proceeding I will roughly summarise the general disadvantages of these two processes.

(1) Both of the processes are expensive from the production point of view, especially in the case of thin sheet metal structures and using rivets of special alloys. The cost of drilling or punching holes and filling them up with rivets, whether headed by hand or by means of riveting appliances, is of necessity high, the whole sequence of operations taking up a great amount of time.

(2) In the case of thin sheet metal structures the rivet spacing is limited owing to the tendency for tearing to take place if the pitch is too close, and to obviate this a double row of rivets has frequently to be used.

(3) In some of the special materials, such as are used in the construction of aircraft, punching is not the best method of making the holes, and in certain cases it is necessary to ream the holes before fitting the rivets.

(4) There is always the possibility of fatigue cracks commencing from the sharp edge of a rivet hole. Further, should the rivet not fill the hole satisfactorily, play and its consequent wear soon develop. On the other hand, should the rivet be too tight, buckling and distortion occur, which it is by no means easy to correct.

In view of these disadvantages one is not surprised at the rapid rise to favour of welding as a production or constructional process.

In the aircraft industry where, in this country at any rate, our designs and production methods change and progress slowly but surely, welding as a safe and economical means of construction has not as yet taken its rightful place.

Anthony Fokker has for the past 22 years used welding exclusively in the construction of his fuselages and empennages with the utmost success, and on this record alone the safety and general suitability of the process may be accepted.

In this country it is only during the past seven or eight years that welding, apart from the manufacture of details and unimportant components, has been used to any great extent, and only then by a few of the manufacturers.

It is now some considerable time since the Avro " Tutor " was adopted as the standard training machine of the Royal Air Force, and I think I am correct in saying that this was the first design to be officially accepted with an all welded fuselage and empennage.

A few of the advantages of welded tubular construction, which incidentally would show up more under war time rather than peace time conditions, are as follows :—

(1) *Economic.*—The whole process is quicker and less costly than riveting and bolting, or the strut and socket type of structure. If desired the whole fuselage frame may be manufactured and assembled with the minimum of costly machine shop operations or tools. This is of paramount importance in time of war owing to machine shops not being capable of rapid expansion. In the case of an aircraft of an all-up weight of 4,300lbs. having a welded fuselage, the saving in cost of production on small quantities with a considerable amount of free hand work would be approximately 25 per cent. over other more conventional types of structure.

Where the job is fully tooled up, the saving would be about 40 per cent. together with a 50 per cent. saving in tool cost.

There is, with welded construction an enormous saving in time, there being fewer parts and therefore less travelling about between operations. A further advantage is that the whole fuselage structure or empennage construction may be made a self-contained unit.

Similar savings may be effected by the use of welded empennages compared with the other types.

(2) *Labour.*—There is an abundant supply of suitable labour and the training of extra labour may be quickly carried out.

(3) *Serviceability.*—This type of structure can withstand rough handling and it is easy for major repairs to be carried out in the field. In the latter case no expensive machinery or equipment is required and no large supplies of fittings and sockets, etc. In place of these a supply of tubing, sheet, and a portable welding set are normally all that would require to be carried to enable almost any class of repair to be effected.

(4) *General.*—Another advantage which I feel ought to be mentioned here, is the fact that with this type of construction a more rigid structure is obtained, and that in the event of a bad crash the occupants have a better chance owing to the good shock absorbing qualities and freedom from splintering, which are inherent in structures of this type, owing mainly to the use of relatively ductile materials.

(5) *Material Supplies.*—The possibility, should occasion arise, of the standardisation of material supplies, one specification for tubing and another for sheet would cover the whole of the steel parts on an airframe structure, with perhaps the exception of the main plane spars and ribs.

(6) The simplification of work in the drawing office, no time being taken up in the design and drawing out of complicated joint fittings.

Turning to the more practical side of the job, I understand welding to mean " the joining of two or more metallic articles by the application of heat, and in

some cases mechanical pressure, in such a manner that the junction zone of the member joined forms as homogeneous a whole as possible." This end may be attained by several welding processes, but I will confine my remarks to-night, with the exception of brief references to other processes, to the following :—

(1) The oxy-acetylene gas welding process.

(2) The electrical resistance process of spot and seam welding.

The oxy-acetylene process has been extensively used in the production of the following components :—Fuselage structure, empennage components, detail fuselage and wing fittings, light alloy petrol and oil tanks, etc.

The electrical seam welding process is used in the production of main plane and other spars and the spot welding process in the manufacture of wing fittings, cowling formers, cowling and fairings. There is also a possibility of its future use in the construction of stressed skin structures.

Oxy-Acetylene Gas Welding.

This is the process in general use at the present time for the welding of detail fittings and tubular members, etc. The blowpipe should be light, handy, well balanced and preferably fitted with dual controls to enable the oxygen and acetylene to be adjusted independently.

Whether the high pressure or the injector type is used is entirely a matter of personal preference as also is the matter of generated or dissolved acetylene gas.

The welder should receive instruction in the correct adjustment of the blowpipe so that the correct welding flame may be maintained to suit the particular class of material being welded. The correct neutral welding flame produced by the combustion of oxygen and acetylene has in its centre a small white cone, at the apex of which the temperature is approximately 3,500°C. Three major types of flame are possible, namely, carburising, neutral and oxidising.

The use of a welding flame having an excess of acetylene may, under certain conditions, cause the normal carbon content of the material to be increased, resulting in hard and brittle welds.

Using an oxidising flame there is a danger of decarburisation occurring together with the possibility of oxide inclusion and network around the grain boundaries, resulting in weak and brittle welds.

It should be remembered that, whatever the work in hand, the oxygen pressure should be the lowest which will allow satisfactory welding, in order to ensure freedom from overheating and oxidisation.

These latter defects may also be caused by the welder using a size of tip which is larger than necessary or by him holding portions of the work to be welded under the blowpipe for a greater length of time than is reasonable.

Cracking and Distortion.

Everyone who has been in any way connected with welding must at some time or other have encountered trouble due to cracks, originating near to the weld, and distortion. I will try, therefore, to offer some reasons for these troubles and at the same time suggest the methods to be adopted for their prevention.

Volume Changes.

It is, of course, generally known that most metals expand when heated and they contract on cooling. Steel is no exception to this rule, although it exhibits certain peculiarities with regard to its expansion and contraction which must be taken into account. During welding, as the steel is heated, expansion occurs in a normal manner until at a given temperature (which varies with the analysis) it begins to contract even though heat is still being applied and finally again starts to expand until melting occurs.

During cooling the steel starts to contract until a certain temperature is reached when it commences to expand and finally contracts in a normal manner.

Now the effect of these volume changes in a fitting or structure being welded is very important. Taking the case of a material heated to a high temperature and cooled quickly, as occurs during welding, this critical expansion on cooling has not time to take place and one is left with a permanent contraction in the material near the centre of the weld.

The adjacent portion, however, will not have been heated to so high a temperature and its rate of cooling may have been slow enough to allow the critical expansion on cooling partially to occur.

Farther away still from the centre of the weld the material will have cooled slowly enough to enable the whole critical expansion to occur. Working away from the weld then it will be observed that certain alterations in volume have occurred in the metal, giving rise to stresses at the boundaries of areas of different volumes, and these stresses, apart from causing distortion, may be sufficient to produce cracks, especially if the structure is in any manner restrained.

Stresses in the material are not produced when two portions of a piece of steel are cooled slowly and at the same rate from a high temperature, but only when cooled quickly or at different rates. These volume alterations are, of course, smoothed out by reheating the part and cooling at a sufficiently low rate.

Quite a lot of distortion and cracking may be avoided by:—

(*a*) Careful preheating of the parts before welding, especially if of different mass.

(*b*) Allowing the parts to cool freely away from draughts, and without any mechanical restraint. This prohibits the use of jigs except for tack welding operations.

(*c*) Always commence to weld in the middle of a seam and work towards the ends.

(*d*) Always weld toward the free edge of a plate fitting and not away from it.

(*e*) In welding a triangular gusset plate into position between two or more tubes commence the welding at the apex and work towards the base.

(*f*) All plates of 14 G. or thicker should have their edges chamfered 30-45° to facilitate obtaining satisfactory penetration and fusion without the tendency to overheat the surface of the plate.

(*g*) During the welding of medium tensile cold drawn tubing, especially streamline sections, cracking sometimes occurs. This is generally due to the stresses which remain in the steel as the result of cold working. The cracking occurs when the section alters in shape on the release of these stresses, and the force tending to change or distort the section is sufficient to cause a crack in the white hot weld metal.

To prevent this the operator should carefully play over the tubing adjacent to the place he intends to weld with a blowpipe until an even temperature of approximately 500°C. is attained. This temperature is quite sufficient to relieve the locked up stresses without materially affecting the crystalline structure of the steel.

Nearly all the foregoing troubles may be prevented by suitable instruction of the operator together with periodical check tests to ensure that the requisite standard is being maintained.

Materials (Steels).

Nearly all of the materials in general use in aircraft construction which are covered by D.T.D. or B.S.I. specifications may be satisfactorily welded by one process or another, especially if subsequently heat treated.

Where subsequent heat treatment is impracticable it is advisable, and in certain instances essential, to use the low carbon, the carbon manganese and the chromium molybdenum series of steels.

TABLE I.

COMPOSITION AND PROPERTIES OF WELDABLE STEELS.

SPECIFICATION. B.S.I.	2S3	C. %	Si. %	Mn. %	S. % Max.	P. % Max.	Ni. %	Cr. %	Mo. %	Remarks.	Ultimate Stress. Tons/sq. in.	MATERIAL
		0.20 to 0.30	⩾0.30	⩾0.60	0.50	0.05	—	—	—	—	⩽28	Mild steel sheets hot rolled.
,,	2S21	⩾0.25	⩾0.30	⩾1.0	0.05	0.05					25 to 35	"20" carbon steel.
,,	T35	⩾0.30	⩾0.35	⩾1.75	0.05	0.05	—	—	—	Before welding After welding	⩽35 ⩽30	35-ton steel tubes.
,,	T45	⩾0.30	⩾0.35	⩾1.75	0.05	0.05	—	—	—	Before welding After welding	⩽45 ⩽30	45-ton steel tubes.
D.T.D.	41	⩾0.18	⩾0.30	⩾0.50	0.05	0.05				Yield 28	⩽30	Mild steel tubes.
,,	61	0.25 to 0.55	2 to 3.5	0.6 to 1.25	—	—	24 to 28	15.5 to 19	—		— —	Stainless welding wire.
,,	82A	⩾0.10		⩾0.60	0.05	0.05	⩾0.2	—	—			Iron welding wire.
,,	102	⩾0.15	⩾0.50	—	—	—	⩾1.0	⩽12.0	—	⩽Yield 30	⩽35	35-ton non-corrosive steel tubes.
,,	124	⩾0.30	⩾0.30	⩾1.75	0.05	0.05	—	—	—	—	⩽30 after welding	Carbon steel strip.
,,	126	⩾0.30	⩾0.30	⩾1.50	0.05	0.05	—	—	—	—	⩽40	Carbon steel bars.
,,	146A	⩾0.20	⩾0.60	⩾1.0	0.05	0.05	1 to 3	16 to 20	—	⩽0.1% Pf. 30	⩽40	High chromium non-corrodible sheet and strip.
,,	166A	⩾0.20	⩽0.50	⩾1.0	0.05	0.05	⩽6	⩽12	—	0.1% Pf. 40-50	52 to 70	Chromium nickel non-corrodible sheet and strip.
,,	167	0.25 to 0.45	0.10 to 0.30	0.40 to 0.80	0.05	0.05		0.80 to 1.2	0.15 to 0.30	⩽Yield 40	45	Cr-Mo 45-ton steel tubes.
,, ,, ,,	171A 176 207	⩾0.20	⩽0.50	⩾1.0	0.05	0.05	⩽6	⩽12	—	0.1% ⩽Pf. 15	35	Austenitic non-corrodible sheet, bar and tubes.

In the two latter cases I consider that the carbon and the manganese content should be kept as low as possible where the material is to be gas welded.

With these two steels, slight air hardening occurs near the weld, especially if the carbon and manganese content are on the high side.

Full advantage cannot be always taken of the superior physical properties of these two steels, as one does not always have a free hand in the dimensioning of primary structural members and the consequent saving in weight is not fully realised.

Of the two steels the chromium molybdenum appears to be slightly superior from a strength point of view and behaves better under the blowpipe, having a nice docile pool when molten.

The addition of manganese and molybdenum to plain low carbon steels causes a certain amount of grain refinement in the " as welded " condition which is desirable apart from the improved physical properties which such additions confer.

The three classes of steels mentioned, whether in tube or sheet form, may be satisfactorily welded without flux, using a good quality welding wire having a composition conforming to D.T.D. 82A specification.

Carbon	...	...	...	0.10 per cent.
Manganese	...	...	...	0.60 ,,
Sulphur	...	...	...	0.05 ,,
Phosphorus	...	...	...	0.05 ,,
Nickel	...	...	...	0.20 ,,

It is not sufficient to use any wire having the above analysis, the wire must be free from oxide and slag inclusions and must be free from rust and grease externally.

Stainless Steels

If of the austenitic type and containing additions of elements which render them non-susceptible to weld decay may be used in the " as welded " condition. Such steels are covered by specifications D.T.D. 171A, 176A and 207.

Stainless steels of the " Twoscore " class are generally put into service in the hardened and tempered or tempered only condition.

The welding of these non-corrodible steels may be satisfactorily carried out, using welding wire to specification D.T.D. 61, and without the use of a flux.

Very careful flame control is essential, the smallest possible excess of acetylene being present.

On no account should an excess of oxygen be present as chromium would be removed from the metal and chromium oxide would be formed, giving rise to unsound and brittle welds.

Considerable care is necessary in the welding of these steels, and it must be remembered that they have a higher thermal expansion than ordinary steels and that the distortion will consequently be greater, so that suitable allowance should be made when setting up.

It is also advisable to weld on one side only and, if this cannot be done, it is advisable to de-scale the part before welding the reverse side.

Aluminium and Aluminium Alloys.

These may be satisfactorily gas welded with perhaps the exception of duralumin.

The pure aluminium sheet to specification L.4, which is mainly used for tanks, cowlings and fairings, is easily welded. The essential requirements are a good quality flux and a quick welder.

A suitable flux conforms to specification D.T.D. 119 and should have the ability to dissolve the oxide quickly and float it away from the weld. The melting point must also be lower than that of the metal. A flux is necessary in aluminium

welding to dissolve the oxide, as the melting point of the oxide is greater than 2,700°C. compared with that of 650°C. for the base metal.

When repairs are to be carried out to a welded aluminium component which has been anodically treated, it is essential that the hydroxide film be thoroughly removed before commencing to weld, otherwise cracked welds will result.

As a welding wire, a strip of its own material has been found the most satisfactory, and where castings are to be welded into position an aluminium welding wire containing 8 or 9 per cent. of silicon is more suitable.

It is essential that all traces of flux be removed by giving a thorough washing in boiling water, otherwise severe corrosion will soon take place owing to the flux being hygroscopic.

Magnesium Alloys.

Any good aluminium welder can satisfactorily weld alloys of this type such as "electron," using a strip of the base metal as a filling wire and using a similar flux to that used for aluminium.

The main criterion of a flux for light alloy welding should be as to whether or not it suits the operator's speed of working. Some operators cannot produce satisfactory welds using a flux which suits another operator and *vice versa*.

Magnesium alloys are used in the manufacture of petrol and oil tanks and fairings, etc.

Other non-ferrous alloys, such as monel metal, brass, etc., may be satisfactorily welded if desired, but have only found limited use in aircraft construction.

Types of Joints.

The simplest form of joint consists of a plain circumferential butt weld between two tubes of the same gauge and diameter, made by placing the two free ends 1/32 or 3/64 of an inch apart and welding together. A slight advantage in strength is obtained by the use of a scarf butt weld, the angle of the scarf being about 45°.

Butt welds, generally speaking, should not be used when the joint is subject to bending, except for minor components, without some method of reinforcement. This may be done by:—(1) Inserting a liner before welding and subsequently pinning the free ends. (2) By fitting an external sleeve with scarfed ends. (3) By welding on stiffening or finger plates at each side of the weld.

Where two tubes of different diameters are to be joined, the smaller should be inserted into the larger and the end of the larger tube fish-mouthed, the angle of the Vee not exceeding 60°.

Joints such as a strut to a longeron are quite common and may be a plain 90° butt weld with the edge of the abutting member roughly shaped to fit in the longeron.

On production, of course, the ends are not snipped out, but are end milled to shape.

The stiffness and strength of these joints may be increased by welding in reinforced plates or tubes; these may also be used for the attachment of bracing wires.

The attachment of fittings or lugs, apart from welding directly to the structure, may be carried out by using wrapper plates and welding distance tubes into position through the strut or longerons. The fittings may then be made detachable and this facilitates maintenance and repair work.

Repairs.

With a welded structure repairs may be readily carried out wherever there are supplies of gas.

It is only necessary to cut away the damaged tube by means of a hack saw and insert a fresh piece of tubing, using a small split internal liner at each end

to locate the ends before welding; the joint may occur anywhere except in the middle third of the tube length.

Where local damage has occurred near to a joint, this may readily be repaired by welding on a small patch plate of a length $3\frac{1}{2}$ inches longer than the damaged portion. Before welding, the structure should be carefully packed up so that the welded joints are free from stress during welding.

Electrical Seam Welding.

This process has been used in the manufacture of main plane spars from nickel chromium steel strip to specification D.T.D. 54A.

The particular spars have been of the conventional three-piece type, two booms and a web, produced by the usual draw-rolling operation.

The booms are roughly assembled to the web and the whole spar is then passed through guide rolls into the seam welder and between two pairs of electrode discs.

The current is continually flowing between upper and lower electrodes, so welding the booms to the web.

The finished weld consists of a series of spots or stitches about nine to the inch and this is obtained by using a motor-driven variable inductance motor which varies the peak welding current and causes intermittent or stitch welding. By varying the speed of this motor, or modulator, the pitch of the welds may be altered at will.

The whole process is very satisfactory and a 15ft. spar may be assembled in three minutes, coming out of the machine perfectly straight.

The spars have to be subsequently heat treated to give the desired physical properties by means of the tension electrical process. Comparative vibration tests carried out on seam welded and riveted "Tutor" spars show that the welded spar develops a slightly higher stress, failure finally occurring through the web failing at a rivet hole used for the attachment of the loading box.

TABLE No. II.

Comparative Test on Riveted and Welded Spars.

Test No.		Amplitude.	Stress Tons/sq. ins. Calculated.	Stress Tons/sq. ins. Actual.	No. of Reversals.	Result.
1	Riveted	0.066"-0.132"	8-16	—	3,764,800	Satisfactory.
	Welded	0.066"-0.132"	8-16	—	3,764,800	Satisfactory.
2	Riveted	0.066"-0.186"	8-22.5	—	3,764,800	Satisfactory.
	Welded	0.066"-0.186"	8-22.5	—	3,764,800	Satisfactory.
3	Riveted	0.066"-0.316"	8-38.3	7.42-33.6	3,764,800	Satisfactory.
	Welded	0.066"-0.316"	8-38.3	7.38-33.7	3,764,800	Satisfactory.
4	Riveted	0.066"-0.353"	8-42.7	7.42-36.9	96,800	Web failed.
					104,200	Btm. boom failed.
	Welded	0.066"-0.353"	8-42.7	7.38-38.2	141,550	Btm. boom and bottom of web failed.

Spot Welding.

The electrical resistance process of spot welding has not received the attention which so useful a production process merits.

Main plane spars have been produced by this method, but the seam welding process is more satisfactory for such components.

Spot welding shows up to good advantage when used in the manufacture of ribs, fuselage and wing fittings, cowlings and general sheet metal parts, whether in steel, aluminium or aluminium alloys.

There are several aircraft in existence in this country having seam welded spars, spot welded steel wing fittings and spot welded aluminium ribs.

Electrical resistance spot welding consists essentially of clamping two or more pieces of metal to be joined between copper electrodes under pressure and passing a heavy current of low voltage from one tip to the other through the metal to be welded.

The electrical resistance of the two contacting faces and the column of metal between the electrodes is greater than that of the electrodes and the column is raised to welding heat whilst under mechanical pressure and fusion occurs.

The factors governing the amount of heat in a weld are:—

1. The current.
2. Time of passing current.
3. Electrode pressure.

These and other variables materially affect the resulting physical and metallurgical properties of the spot welds, and it is the accuracy with which these are controlled that determines to a large degree the success or failure of the process.

The mechanical pressure is, of course, readily controllable and the magnitude of the welding current is in most cases governed by selecting the correct transformer tapping to suit the material being welded.

The time of passing the welding current is rather more difficult to control, but may be done by means of relay-operated contactors, synchronous motor-driven switches, or by mercury valves, having grid control.

The last mentioned type is preferable as it is free from the troubles due to arcing and wear which are always associated with contactors and synchronous motor switches. It is capable of controlling the welding time from 0.01 sec. upward. Such accurate control of welding conditions does not appear to be really necessary when considering the ordinary steels, but it becomes essential in the welding of non-corrodible steels and light alloys. The following table gives the mean results obtained, using a spot welder with automatic control, in the welding of the ordinary steels:—

TABLE III.

Material.	M.S. Sheet.	B.S.I. Spec. 2 S 3.
	Load per Spot.	
Gauge.	Single Shear.	Double Shear.
22	1,100	1,700
20	1,600	2,300
18	1,900	2,700
17	2,400	3,400
16	2,500	4,200
14	3,400	5,600
12	3,900	6,600
10	5,800	8,400
Material.	Carbon Steel.	D.T.D. Spec. 124.
18	2,700	4,400
16	4,400	6,700
14	5,600	8,700
12	6,700	11,000
10	7,600	13,000

In the welding of the non-corrodible steels and light alloys contactor operated welders are not suitable. With these materials it is essential that the structure of the material on the outsides of the spot is unaffected by the welding heat, and this necessitates extremely short welding times ranging from 0.01 to 0.08 sec. together with fairly high currents, otherwise the corrosion resisting properties would be seriously impaired.

Using contactor controlled equipment on a 50-cycle supply, the variation in operation of the contactor determined by oscillographic tests may be as much

as two cycles, and as under certain conditions of welding this variation may be 70 per cent. of the total welding time, consistent results are almost impossible of attainment.

Numerous tests have been carried out on Alclad to specification D.T.D. 111 welded on an ordinary welder with contactor control which have given very satisfactory physical properties, although the variation has at times been rather large due to insufficient control of the time of passing current and also owing to insufficient amperage being available. Table No. IV gives the average figures obtained for different gauges:—

TABLE IV.

Properties of Light Alloy Spot Welds.
Load per Spot in Pounds.

Gauge.	Single Shear.	Double Shear.
26	168	308
24	243	392
22	336	530
20	425	952
18	458	951

It will be noted that as the 18s G. material is approached that there is a falling off in the strength; this is entirely due to the capacity of the machine being approached.

A large number of tests carried out on similar material, welded by means of remote electrodes and mercury valve grid controlled equipment, have shown an improvement on these figures of 15 to 20 per cent.

It should be pointed out that this does not represent finality, as numerous tests remain to be carried out before it can be decided what is the correct relationship between current pressure and time for optimum results in a given thickness.

There is, however, little doubt that with controlled conditions welds may be consistently produced which are strong, sound, and which do not penetrate to the outside surfaces of the material. As a result of these investigations I feel that the day is not very far distant when electrical spot welding will find extended use in aircraft construction and the possibility of stressed skin structure being manufactured by this method should not be overlooked.

Modern methods of stressed skin construction, whether for fuselages or wings, are of necessity expensive owing to the enormous amount of riveting entailed, and if such structures can, in future, be fabricated by spot welding, using remote electrode, a considerable saving in manufacturing costs may be effected.

There are no grounds for assuming that a structure fabricated in such a manner will be any less efficient than a riveted structure.

Arc Welding.

The electric arc welding process, which in other fields is rapidly gaining ground, is of little interest in the welding of aircraft structures. Difficulty is experienced in welding very thin sections, the finished welds do not have a good appearance and it is not as handy for welding in sharp corners.

The training of operators, especially for welding thin gauge materials requires a greater length of time and the equipment is not as simple or as easily transportable as the oxy-acetylene equipment.

Mention should be made, however, of the hydrogen arc or atomic hydrogen process. This process, although it may not be suitable for general use, shows distinct promise in the welding of non-corrodible steels and in the welding of spars and similar components. Except in the case of edge welding, this process becomes rather awkward to apply to fillet joints in material thinner than 0.04in.

A good oxy-acetylene welder will find no difficulty in becoming a good atomic

hydrogen welder. The welding conditions, when using this process, are automatically strongly reducing, but never carburising.

Molecular hydrogen, passed through an A.C. arc between two tungsten wires, is split up into atomic hydrogen. A flat flame is produced, at the end of which the heat absorbed in splitting up the molecules is liberated, when the atoms recombine. This flame is used in a similar manner to the oxy-acetylene flame to melt the filling wire into the weld.

Oxygen is totally excluded from the weld by the burning hydrogen and the atomic hydrogen is a reducing agent capable of reducing the most refractory oxides, welds made by this process being entirely free from inclusions.

Discussion.

Captain Young: It had been suggested by the authors that gap welding should be used because one was building up a structure in a jig; on the other hand, it was said that jigs were used in connection with contact welding. He asked if there were any objection to contact welding.

Major Wylie (*Fellow*): He felt that in regard to the subject of spot welding the authors had stopped short just at the point at which it was becoming particularly interesting. He referred to the new spot welding apparatus with the thyratron control, and said there seemed little doubt that very excellent, reliable and uniform spot welds could be produced, the weld material not extending to the surface, so that resistance to corrosion was not entailed. There was no doubt that work done by that machine could be very excellently connected together. But the real problem with the new stressed skin structures was that most of the parts to be joined together could not be brought to the machine; the machine had to be taken to the assembled part. He asked for Mr. Taylor's views with regard to rendering the welding pincers sufficiently portable to be able to connect the pieces together—say, on a fuselage or a stressed skin wing.

Mr. A. E. Bingham (*Associate Member*): It seemed to him that welded construction called for very rigid inspection and control, no matter whether the welds were line or spot welds; on the other hand, one could inspect riveted joints very easily. If one were a little doubtful about a rivet, one could knock its head off and put in another, but with welding, especially spot welding, it was almost impossible to ensure, when on the job, that it was satisfactory; one could not cut out a joint, because that would mean cutting the job in half. He believed that was one of the chief reasons for resistance to the progress of welding, especially in the case of aircraft, in which inspection was of paramount importance.

Mr. J. V. Connolly (*Associate Fellow*): He emphasised the importance of inspection and control, particularly in connection with spot welding, and he asked the authors how they ensured the accuracy of the welding or how they inspected or controlled it. They had referred to flame control and the necessity for using a flame which was neither carburising nor oxidising, but they had assumed that the welders could be trained to a standard sufficiently high to ensure that they always produced perfectly satisfactory welds. Probably they were quite right in that regard, because he had never seen or heard of an aircraft weld failing. He mentioned some machines with welded steel fuselages which had flown for more than 6,000 hours but had given no trouble so far as the welding was concerned. Apparently the problem of inspection and control either gave no trouble or was adequately dealt with by Messrs. A. V. Roe and Company, and it would be interesting to learn what method was adopted. If the matter were adequately covered and if the welders did always produce good welds, it would seem that the resistance offered by many people to the adoption of welding was groundless, and they would do well to take more advantage of a very valuable tool. Most of the major aircraft firms did not use welded steel fuselages at all in military aircraft, perhaps because the specifications for the machines were such as to exclude welding automatically. It would be interesting to hear

whether there were any hidden difficulties in the process which had not been mentioned in the paper.

Mr. H. SUTTON (Royal Aircraft Establishment) (*Fellow*): There was a great deal of wisdom in the paper; very few important matters with regard to aircraft welding had been left out, and the Society was fortunate in having a paper on the subject from authors having such wide practical experience and knowledge. The authors should be congratulated on the stitch welding of spars, which seemed an eminently sound job, capable of very useful application. It would be interesting to hear the authors' views as to the scope of spot welding in building up fuselages and wings; did they visualise the building up of such members by putting on small pieces gradually or building up units and finally attaching them to each other? Another question was whether profiled pieces could be pressed together so easily and so nicely as one imagined they must be in order to produce a really good spot weld. When test pieces were prepared, one made smooth-rolled flat specimens which were ideal, but he was wondering whether in regard to the pieces used in practice the story might be quite different.

Referring to acetylene welding, Mr. Sutton said there seemed a prevalence of the opinion that the effect of passing the torch over a weld for the second time was not good from the point of view of the strength of the weld, and he asked if the authors had had any experience of that. He asked whether, in the event of the failure of a weld—as for instance when a machine was damaged—it was usual to cut away all the weld material and start anew, because one would imagine that that course would be advisable if indeed it was not a good thing from the strength point of view to pass the torch over the weld for the second time.

The subject of spot welding was of tremendous interest and the figures for the Alclad type of joint as compared with ordinary duralumin were nothing less than surprising, in view of the thin skin of pure aluminium on the surface. One might suppose that when the two thin skins of pure aluminium were joined together, the resulting joint would not be very strong. It was pleasing to hear that the fusing of a considerable portion of metal brought potentially some of the duralumin into the joint, and that the shear strength values of the joints obtained by the authors were gratifying.

Mr. E. W. FORSTER: With reference to the authors' use of a motor-driven variable inductance motor for control of seam welding and the statement that grid controlled valves were very desirable or even necessary for spot welding, he said that surely the latter statement was equally applicable to seam welding, since seam welding was a series of spot welds. A reason for the desirability of using the grid controlled mercury vapour valve was that the ratio of welding time to total time could be varied very readily. With regard to the inaccuracy of the use of contactors for short times, the authors had mentioned that it was possible to have a variation of two cycles on a 50-cycle supply; that would represent an error in the neighbourhood of 400 per cent. if welding times of the order of 0.01 second were required.

Referring to the spot welding of Alclad, Mr. Forster asked the authors what types of electrodes were used. Was it necessary to use a copper alloy for the electrodes? It seemed that the problem of accurate time control of welding current in resistance welding, whether applied to seams or spots, had been solved by the use of grid controlled mercury vapour valves, but it appeared that much investigation had yet to be done on the form and material of the electrodes themselves.

No reference had been made in the paper of the electrical power necessary to secure satisfactory resistance welding of aluminium and light alloys such as Alclad, but as the energy required is considerable it would be of great interest to those concerned with the manufacture of aeroplane parts to have some idea of how much power was required for certain gauges of material. It was quite

evident that about three times as much power was required for welding aluminium alloys as for welding a similar gauge of mild steel.

Captain J. LAURENCE PRITCHARD (Secretary of the Society): He recalled a visit he had made to America and Canada some six years ago, when he had noted that welding was being applied to aircraft construction on a large scale. For some years the Americans and Canadians had been building welded fuselages in particular, and those fuselages were perfectly satisfactory. It had taken them in this country a long time to reach that stage. That was due not only to the caution of the Air Ministry but also to the attitude of the leaders of the industry themselves. Among the many people attending the meeting to hear the paper on the jointing of materials by welding, there were only about three leaders of the industry; he regretted that he could not see more of them present, because the problem of the application of welding to aircraft construction was one of very great importance. When in America he had been told that when machines having welded fuselages met with accidents the risk of a major disaster was much less than with ordinary tubular fuselages, and that was a distinct point in favour of welding. He had seen in America many hundreds of tests of welds and there was not one case among them in which a weld had failed; in every single case the metal had failed before the weld. It was the old story of the glue being stronger than the wood, and he could not understand why they in this country were still so slow in taking up welding. He asked what amount of skill was really required to produce good welds, and whether they in this country were inventing a particular kind of skill because they did not like to put unskilled people on to the work. Welding seemed to him one which was easily controlled. He also asked whether it was possible to inspect welds by means of X-rays.

The problem of repairs was one which worried him, entirely from a stressing point of view. The repairs he visualised were those that would be necessary in the event of war, when machines would have to be repaired in the field. He wondered what would be done when a machine had crashed and was badly bent, and how it would be straightened before one started to weld it. A certain amount of straightening and cutting away would be necessary, and, judging by some of the pictures which had illustrated the paper, it would seem that the authors would be prepared to cut away nearly everything and to leave nothing but the welds!

Mr. GEORGE JEWET: What happened to the pure aluminium and duralumin when Alclad was spot welded? Was corrosion likely to occur immediately around the weld, and if so, what treatment was necessary to prevent it?

Mr. A. C. BRAND: The production of a sound weld by means of gas was a matter of craftsmanship and one could reasonably form a judgment as to the standard of the weld. In regard to seam welding, however, the authors had mentioned the achievement of the optimum condition, in view of the variables in connection with current, time, and so on, and it did seem rather difficult to find an easy means of ensuring that the optimum condition was in fact achieved. He asked if the authors could give some information in that connection.

Mr. HORACE MYERS, Assoc.M.Inst.C.E. (Chief Inspector of Stores, Air Ministry) (*communicated*): The authors contend that welding is a good and satisfactory method of producing airframes. Welding is, however, the one process which inspection cannot get inside to verify; and, as the safety of aircraft is vitally dependent on the competency of inspection during manufacture, this inaccessibility is a serious disadvantage. Moreover, the metallic materials now embodied are extremely sensitive; their producers take the most detailed precautions, and would be horrified at the idea of a naked flame impinging on the metal at any stage of its progress through their works. Yet the process of welding, at any rate by the oxy-acetylene method, entails the application of a flame which, unless skilfully controlled, can ruin the material in a space of minutes or even of seconds.

In support of their contention the authors adduce the unquestioned fact that aircraft built up by welding have flown safely for a considerable period. All such aircraft have, however, been constructed by firms who specialise in this method, and the requisite precautions in controlling the details of the process, and in ensuring the requisite skill on the part of the operators, have been unremittingly applied. If and when there is need for a substantial increase in the output, it may prove impossible to obtain except by spreading the work over a large number of firms—probably acting as sub-contractors. It is extremely unlikely that at each and every such works the optimum conditions at present prevailing can be ensured. Since these conditions constitute the only real safeguard against faulty welding, the prospects seem to be far from reassuring.

The authors consider that emergency repairs " in the field " by welding will present no difficulty. The aerodynamical behaviour of an aircraft depends absolutely on the maintenance of the true form of its various components in themselves and of their correct alignment relatively to each other. If these are not maintained the aircraft ceases to behave as the designer intended, and may easily become uncontrollable; this is especially to be feared if the fuselage distorts. It is not easy to believe that emergency repairs carried out by welding under conditions of great difficulty, and lacking all the special appliances provided during manufacture, can be relied on to leave the structure in anything approaching " truth "; nor can a welded framework be readily adjusted if it is found to be " out of truth." Here again the outlook is disquieting. He would emphasise that these are purely personal views, and must not be taken as representing the considered opinion of his department or of any of his colleagues.

Reply to the Discussion.

Mr. Taylor: Replying to Captain Young's reference to gap welding versus contact welding, and the question as to whether there was any objection to contact welding, he said that little reference was made in the paper to either gap or contact welding, apart from the statement that plain circumferential butt welds were made between tubes by placing the free ends $^1/_{32}$ or $^3/_{64}$ of an inch apart and welding together. But if, for instance, one were contact welding some tubes in a jig formed on a table by means of wooden blocks, as he had illustrated during the lecture, and if the centre lines of the two longerons were to be 3ft. apart finally, the centre lines of the blocks would be arranged 3ft. plus $^3/_{32}$ of an inch apart. Then the struts could be machined and milled to that length and would make a snug fit between the two longerons; they would then be welded. In such a case, where there was no gap, the contraction was usually slightly greater than when there was a gap, and by making the allowance mentioned it would be found that the longeron centres would be 3ft. after welding. In the case of repair it was necessary to watch that rather carefully; when putting in a diagonal strut he very seldom made it a tight fit but preferred to leave a little gap so that the distortion due to contraction was not so great; if there were no gap, the tail end of the fuselage would be pulled over. From the welding point of view, using thin gauge tubes, it did not really matter whether there was a close fit or a slight gap.

He agreed with Major Wylie that the paper had stopped short at the point where the results of spot welding were becoming interesting. The reason was that, owing to a little bad luck, the equipment he was working with was not at the moment available for tests, but it would be available within a week or so.

Dealing with Major Wylie's remarks with regard to making the pincers more portable, Mr. Taylor said that one could weld a structure together piece by piece or could weld a job in units and finally join the units together by spot welding, or by riveting in places where it was impossible to get the electrodes. We should never be able to dispense with riveting altogether, nor should we be able to spot weld everything. At present the apparatus was rather heavy and unwieldy, and the pincers could not be picked up by hand. But it was possible, with the

pneumatic or spring balancers that were used for various jobs of that kind, to suspend or support the weight so that one had merely to pivot it about a point. The fuselage would have to be placed on a rotating jig so that it could be rotated around the electrodes.

Mr. Taylor disagreed with the view that there was less rigid control of welding than of riveting, and said that one had every bit as much control of welding as of any other process. If there were present an inspector who could say whether or not a nut had been tightened up without stripping the thread, or whether a rivet had been nicely closed up, or who could say that there was not a crack from the rivet hole, it would be interesting to have a word with him! With regard to the statement that if a rivet were not fitted satisfactorily it could be knocked out and replaced, he pointed out that in welding also one could cut out a weld and re-weld. Again, one picked the men to do the best jobs in welding just as one did in riveting, the men having proved by periodical check tests that they could maintain a certain standard of workmanship.

He had never heard of specifications excluding welding; Messrs. A. V. Roe and Company had made several types of machines to conform to various specifications and those machines had had welded fuselages and empennages.

Replying to Mr. Sutton's reference to spot welding in wings and fuselages, he said he did not see why in future we should not get the pincers in, although so far it was not possible. After all, it was necessary sometimes to get pneumatic riveters into awkward places, and he imagined that difficulties of that kind would be overcome in regard to welding just as they had been overcome in regard to riveting.

Presumably Mr. Sutton, when referring to profiled pieces, had had in mind burrs on the edges of fittings. Of course, the burrs should be removed first by filing; but even if the burrs were not removed, good contact was obtained between the parts by reason of the mechanical pressure applied when placing them together for welding.

In repairing, it was the endeavour to remove all the added filling wire of the first weld; and, of course, all the scale and oxide must be removed, otherwise it would get into the weld. But it was usually easier to cut away from the weld and to put in a longer length, so that the original weld was cut out altogether. One could not do that in the case of a straight junction, but with longeron replacements it was possible to carry on with a longer piece past a strut joint.

Dealing with Mr. Forster's reference to the motor-driven modulator used with the seam welder, Mr. Taylor said that if he were installing a seam welder to-day he would use the mercury vapour valves; but the particular seam welder referred to had been installed a few years before such control valves had become available, and at that time there was no alternative but to apply the modulation method. For steel, even the modulation method was quite satisfactory. With regard to the " on " and " off " ratio, by means of the mercury vapour valves one could control spot and seam welding at speeds up to 1,500 spots per minute. As to the inaccuracy of the contactors, he said that if the machine were set for passing current for a period of, say, four cycles, and if on top of that there were another two cycles of passing current due to the contactors not opening freely, one experienced the big variation mentioned in the paper. It could in some cases keep up to 70 per cent. of the desired time for passing current. It had nothing to do with the 50- or 60-cycle supply.

The problem of electrode material is not of such great importance as it was a short time ago, because the valves were giving such fine control. Again, the effect of the material on the outside of the sheet is not so great as formerly, owing to the extremely short time of application, and one could almost dispense with the water-cooling of electrodes; the time of application was so short that the transference of heat was not sufficient to cause trouble due to sticking electrodes. The amperage necessary was much greater. With contact or control, on aluminium alloys, it was approximately three times that required

for steel, but where the time was reduced one required a higher amperage still where using the mercury valves.

Replying to Captain Pritchard's questions concerning the skill and the training of welders, he said there was an enormous number of oxy-acetylene welders in this country; they had all learned how to handle the blow-pipe, which was the most important factor. Some people would never learn to weld properly, whereas others would learn with facility, just as some people would never be able to write decently, whereas others learned to write quite easily. Once a man had mastered the art of handling the blow-pipe, it was a case of doing what he was told and of working to certain rules and regulations, and by means of periodical check tests one could maintain strict control of the men. If the standard of a man's work declined, he was not given any more important work. One could always check a man's work by cutting out joints.

X-ray inspection was possible in the case of simple joints, but it was not a very good means of checking longeron joints. One should have the film inside the longeron. It had been done, but one was not always sure of the depth at which trouble existed.

With regard to carrying out repairs in the field, he said that one thing in favour of welded construction was that it afforded two methods of repair, whereas with other types of construction there was only one method. In the case of the ordinary strut and socket type of structure one had to rivet on a patch plate or sleeve. One could always patch a joint in that way in a welded structure if welding facilities were not available. In the repair scheme for the "Tutor" there were means of joining in fresh sections, using external sleeves held by tapered pins. As to the criticism that if a welded structure were damaged it would be necessary to cut away a large amount of it, he said he imagined that it would be necessary to do the same with a welded fuselage as with any other type, *i.e.*, to scrap it.

Replying to the questions concerning the effect of welding upon the outside of an Alclad sheet, he said that if the welding time were very short the material on the outside of the sheet was not affected much by the heat; there might be a slight annealing effect, but he did not think there would be a lot of trouble due to corrosion in that case any more than was likely to occur owing to the difference in physical properties as between rivets and the surrounding sheet material arising from the different degrees of cold work.

Discussing the reference to the variables of spot welding, he said that one could only find the best results, of course, by test. The tests were necessarily rather numerous at first, but once one had determined upon certain conditions which would give results up to the standard required, one could fit a recorder which would indicate whether or not subsequent welds had fallen below that standard. That had had to be done in the case of the seam welded spar, though it was done in perhaps a rather rough and ready way. The machine was set in different ways until the best welds were obtained, and then one or two further welds were tried out and the work was carried on. With the new equipment one could get more information.

The PRESIDENT: In proposing a vote of thanks to the authors for their paper, he said there was nothing he liked more than to listen to men who were pioneers and enthusiasts; but when in addition it was obvious that the authors had enormous experience, as was the case with Mr. Dobson and Mr. Taylor, it was indeed a great privilege to listen to them. He asked the meeting to express both to Mr. Dobson and Mr. Taylor very great appreciation of their paper.

(The vote of thanks was accorded with enthusiasm, and the meeting closed.)

ELASTICALLY ENCASTRED STRUTS.[1]

By N. J. Hoff.

§1. Introduction.

During the last fifty years much experimental and theoretical work has been carried out on the subject of the failure of struts, *i.e.*, rods under axial compression. Most of this work has been devoted to the case of struts pin-jointed at both ends and only a small part examined the behaviour of rigidly encastred struts. From these investigations we know that in case of very slender struts the critical load for rigid encastrement is the fourfold of that for pin-jointed ends. This difference becomes less with decreasing slenderness of the strut,[2] but even for slenderness ratios usually attained in aircraft framework it is considerable, if high tensile steel is used. In actual framework, compression members being more or less rigidly joined to nodes which may twist elastically, they represent a case between both forementioned extremes and may best be regarded as elastically encastred. Since according to above statements the load which may be sustained by a strut obviously depends a great deal upon end constraint, it is of great importance for design purposes to determine exactly the effect of elastic encastrement.

In a previous issue of this Journal[3] a report of investigations concerning elastic distortions of a framework was given. The relative stiffness factor there introduced may also be used with advantage for calculating failure of struts.

Deflections, stress, and critical load of an elastically encastred strut may be put equal to those of a pin-jointed strut of equal size and material but of reduced length λl. In the present paper this equivalent length λl has been computed and graphically represented in function of the relative stiffness factor.

The critical load, *i.e.*, the load under which the strut becomes elastically unstable was the first characteristic value computed (*cf.* §2). In the U.S.A. and in Germany this is regarded as the limiting load of a strut.

Struts do not collapse, however, by reason of elastic instability, but always by reason of failure of the material, as stated by Professor Southwell.[4] Since the stress developed is not only dependent upon the end load, but also upon the quite accidental initial deflection of the strut and eccentricity of loading, the problem is very complex. One practical solution is to compute the critical load and to design struts with a factor of safety high enough to allow for the imperfections mentioned. The other method, adopted in Great Britain, consists in limiting the maximum allowable eccentricity and deflection of struts used in aircraft construction and to calculate stresses for the case when this maximum deviation occurs. The effect of elastic encastrement upon stresses thus calculated has been dealt with in §4.

In §3 stocky struts have been considered and in §5 some general remarks concerning strut failure in frameworks added.

§6 presents results in a concise form.

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[1] Author desires to thank Dr. E. Orowan for his advice, and Mr. J. Torday for his kindness in drawing the diagrams.

[2] *Cf.* §3.

[3] August, 1935, *cf.* Reference 1.

[4] *Cf.* p. 4, Reference 2.

§2. The Critical Load of Struts.

The critical load of a strut pin-jointed at both ends has been deduced and the behaviour of struts under end loads discussed *in extenso* in Messrs. Pippard and Pritchard's "Aeroplane Structures."[5] Here it will, therefore, suffice to give only a brief deduction of the critical load of a strut rigidly encastred at both ends.

The equation for the deflected rod is

$$EId^2y/dx^2 = -M = -P(y + M_e/P) \quad . \quad . \quad . \quad (1)$$

The complete solution of this equation is given by

$$y = a \cos \mu x + b \sin \mu x - M_e/P$$

where

$$\mu = \sqrt{(P/EI)}.$$

Taking the origin of co-ordinates at the middle, as shown in Fig. 1, the sine term can be cancelled for reasons of symmetry. Since the deflection vanishes at both ends we get

$$M_e/P = a \cos \mu l.$$

We may, therefore, write

$$y = a(\cos \mu x - \cos \mu l) \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Since the slope vanishes at both ends we have

$$dy/dx = -a\mu \sin \mu l = 0 \quad . \quad . \quad . \quad . \quad (3)$$

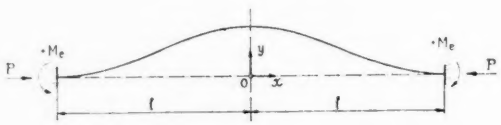

FIG. 1.

This equation is fulfilled when $a = 0$. Consequently the strut may remain perfectly straight under any given end load. The solution $\mu = 0$ is trivial. It means that the strut remains straight in absence of an end load. A solution of importance for the following is found when putting

$$\mu l = n\pi.$$

Setting the expression for μ in this equation and rearranging, we get

$$P = n^2\pi^2 EI/l^2 \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where n may be any integer.

Substituting $n\pi/l$ for μ in equation (2) and dividing by $\cos \mu l$, we get

$$y = c\{(\cos n\pi x/l)/(\cos n\pi) - 1\} \quad . \quad . \quad . \quad . \quad (5)$$

We may, therefore, state that equilibrium between end load as given by equation (4) and elastic forces is possible, if the strut is deflected according to equation (5). Since c is an arbitrary constant it is evident that the strut is in a state of neutral equilibrium, if an end load as expressed by equation (4) is acting. This end load is called the critical load of the strut. In the following it will be denoted by P_c.

Putting $n = 1$ we get the first, smallest value for the critical load. Denoting by L the total length of the strut

$$L = 2l$$

the first critical load becomes

$$P_c = 4\pi^2 EI/L^2 \quad . \quad . \quad . \quad . \quad . \quad (6)$$

which is a well-known formula. Under this load the strut may have a shape like illustrated in Fig. 1 and as given by following equation

$$y = a(\cos \pi x/l + 1) \quad . \quad . \quad . \quad . \quad . \quad (7)$$

[5] *Cf.* p. 83 *et seq.*, Reference 3.

It is obvious that equilibrium between end loads and elastic forces is also present, as shown in Fig. 2, in case of a strut of length $2x_1$ loaded by the critical load calculated by equation (6), if only end moments M_1 have a value equal to the bending moment calculated from equations (1) and (7) for $x=x_1$ and the slope of the neutral axis at the ends of the strut is in accordance with equation (7). In this case the strut in question does not differ in any respect from that portion of the rigidly encastred strut which extends from $x=-x_1$ to $x=+x_1$. Consequently the strut under view is also in a state of neutral equilibrium under the action of the force given by equation (6), which force may be regarded its critical load.

Varying x_1 between l and $l/2$ we get struts of different lengths which all have the same critical load; this is only made possible by the fact that they are constrained at their ends in a quite different but definite manner.

With $x_1=l$ we get the case of the rigidly encastred strut. The slope of the neutral axis vanishes at the ends. With $x_1=l/2$ we have the pin-jointed strut. The second derivative of y and consequently the end moment vanishes in this case. All possible values of x_1 between both extremes represent elastically encastred struts of different grade of encastrement with corresponding values of end moment and angle of twist at the end.

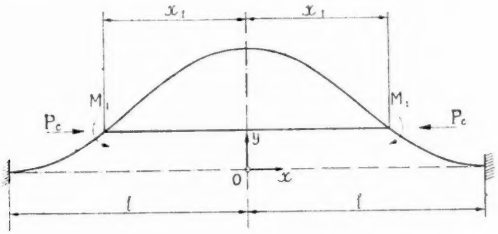

FIG. 2.

Elastic encastrement at the end of the strut may be characterised by a support allowing a twist θ of the end of the strut proportional to the moment acting on the support :—

$$\theta=\Phi M \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The value of Φ may be calculated or derived from experiment. In case the strut is a member of a framework, $1/\Phi$ is the torsional stiffness of the node at the end of the strut. This has been calculated in Reference 1 and results there derived may be applied to the present problem. It was found that the relative stiffness factor (R.S.F.) as defined by

$$\Omega=EI\Phi/l \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

where E is Young's modulus of elasticity, I the moment of inertia of the cross section and l the length of the strut may be used with advantage instead of Φ in calculations.

For solving the present problem we have to compute the bending moment at x_1 which multiplied by Φ must equal the slope at x_1 of the neutral axis as calculated from equation (7). Differentiating equation (7) twice with respect to x we get

$$d^2y/dx^2=-A\,(\pi^2/l^2)\,(\cos \pi x/l) \quad . \quad . \quad . \quad (10)$$

Substituting in equation (1) we have

$$M_{x1}=AEI\,(\pi^2/l^2)\,(\cos \pi x_1/l) \quad . \quad . \quad . \quad . \quad (11)$$

The slope of the neutral axis is given by the first derivative :—

$$dy/dx=-A\,(\pi/l)\,(\sin \pi x/l) \quad . \quad . \quad . \quad . \quad (12)$$

This must equal the twist of the support

$$\theta=\Phi M_{x1}=M_{x1}l\Omega/EI.$$

The value of l, *i.e.*, the length of the strut under view is in the present case

$$l = 2x_1.$$

Substituting and putting the slope equal the twist we get

$$-A\,(\pi/l)\,(\sin \pi x_1/l) = M_{x_1} 2x_1 \Omega/EI.$$

Hence

$$M_{x_1} = -(AEI\pi \sin \pi x_1/l)/(2x_1 l\Omega).$$

If we put this expression equal the expression for M_{x_1} given by equation (11) and solve for Ω we get

$$\Omega = -(\tfrac{1}{2})\,(tg\pi x_1/l)/(\pi x_1/l) \quad . \quad . \quad . \quad . \quad (13)$$

With aid of equation (13) now we are able to determine for any given value of the R.S.F. (Ω) the corresponding length $2x_1$ of a strut characterised by the fact that it has the same critical load as the rigidly encastered strut of the

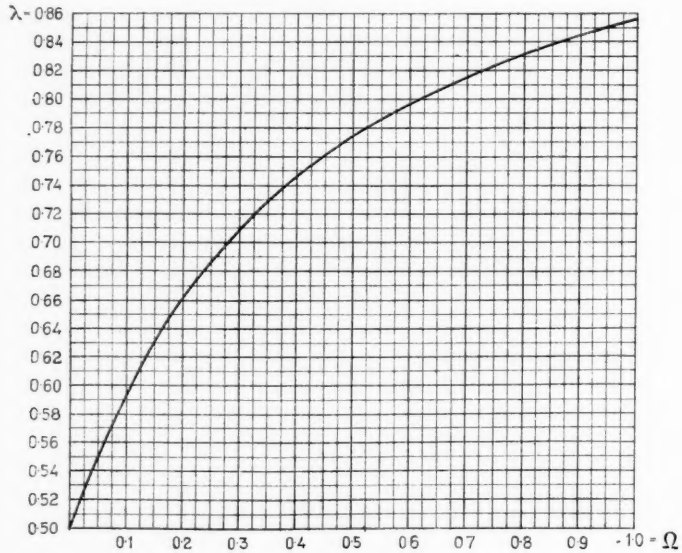

FIG. 3.

EQUIVALENT LENGTH DIAGRAM.
SYMMETRICAL CASE.

length $2l$. Since in equation (6), the expression of the critical load, the length appears in the denominator and at the second power, it is obvious that a strut with elastic encastrement characterised by Ω has a critical load

$$(2x_1/2l)^2 = (x_1/l)^2$$

times the critical load of a strut of equal length and size but rigidly encastred. Since the critical load of the rigidly encastred strut equals four times that of the pin-jointed strut we may state that the elastically encastred strut has a critical load

$$4\,(x_1/l)^2 = (2x_1/l)^2$$

times the critical load of the pin-jointed strut.

With aid of the equivalent length λl we shall in the following refer the critical load of any elastically encastred strut to that of the pin-jointed strut of same length and size. If we write

$$P_c = \pi^2 EI/(\lambda l)^2 \quad . \quad . \quad . \quad . \quad . \quad (14)$$

where l is now the total length of the strut, from our above deductions obviously we get

$$\lambda = l/2x_1 \quad . \quad . \quad . \quad . \quad . \quad (15)$$

By setting different values for x_1 into equation (13) corresponding values of Ω have been obtained. The equivalent length coefficient λ was found with aid of equation (15). Results are shown in the diagram of Fig. 3.

In the non-symmetric case, *i.e.*, when the R.S.F. is different at both ends of the strut we may proceed in a similar way. In this case, however, x_r will differ from x_1 causing a slope of the $x_r - x_1$ line against the base line $2l$. Since in all our calculations we regard only infinitely small deflections, the component of the end load P_e in direction of the strut

$$P_e \cos \rho$$

will differ from P_e by an infinitely small amount which, naturally, may be neglected. The slope dy/dx of the neutral axis of the strut, however, is of the same order infinitely small as ρ and consequently ρ must not be disregarded when calculating the twist due to end moments.

The effect of neglecting ρ may best be seen when computing the critical load of a strut rigidly encastred at one end and pin-jointed at the other. When disregarding ρ we may put

$$x_1 = l \text{ and } x_2 = l/2.$$

With

$$x_1 + x_2 = 1.5\ l$$

we get for the equivalent length coefficient

$$\lambda = l/1.5 \times l = 0.666.$$

Hence the critical load would amount to

$$1/\lambda^2 = 1.5^2 = 2.25$$

times the critical load of the pin-jointed strut. In reality the factor is about 2.04.

The component of P_e perpendicular to the $x_r - x_1$ line equals

$$P_e \sin \rho$$

and the moment of both perpendicular components

$$M_p = P_e\ (x_r + x_1) \sin \rho.$$

For infinitely small values of ρ we may put

$$\sin \rho = tg\rho = (y_r - y_1)/(x_r + x_1).$$

Hence

$$M_p = P_e\ (y_r - y_1).$$

This moment obviously equals the difference of end moments at x_r and x_1 whereby equilibrium of external forces and moments is proved.

Proceeding now with our calculations we have

$$\rho = (y_r - y_1)/(x_r + x_1) \quad . \quad . \quad . \quad . \quad . \quad (16)$$

From equation (7) we get

$$y_r = A\ (\cos \pi x_r/l + 1)$$
$$y_1 = A\ (\cos \pi x_1/l + 1).$$

Hence

$$\rho = A\ (\cos \pi x_r/l - \cos \pi x_1/l)/(x_r + x_1) \quad . \quad . \quad . \quad (16a)$$

With aid of equations (10) and (1) we get

$$(d^2y/dx^2)_r = -A\ (\pi^2/l^2) \cos \pi x_r/l$$
$$(d^2y/dx^2)_1 = -A\ (\pi^2/l^2) \cos \pi x_1/l$$
$$M_r = AEI\ (\pi^2/l^2) \cos \pi x_r/l \quad . \quad . \quad . \quad . \quad (17)$$
$$M_1 = AEI\ (\pi^2/l^2) \cos \pi x_1/l \quad . \quad . \quad . \quad . \quad (17a)$$

With aid of equation (12) we get

$$(dy/dx)_r = -A\ (\pi/l) \sin \pi x_r/l \quad . \quad . \quad . \quad . \quad (18)$$
$$(dy/dx)_1 = +A\ (\pi/l) \sin \pi x_1/l \quad . \quad . \quad . \quad . \quad (18a)$$

In the following we shall denote, as has been in the foregoing tacitly denoted,

a moment positive when acting on the strut in such way as to produce a curvature with its concave side downwards. In Fig. 4 the arrows M_r and M_l show the positive directions. A moment acting on the supports is considered positive when it is the reaction of a positive moment acting on the strut, *i.e.*, when it acts in the inverse direction. The slope is positive, if y increases when proceeding in the positive x direction, *e.g.*, ρ in Fig 4.

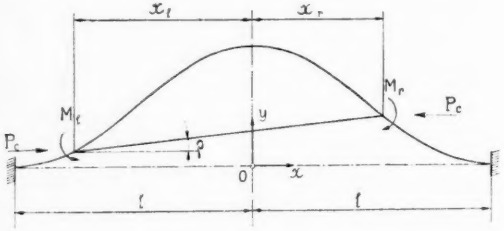

FIG. 4.

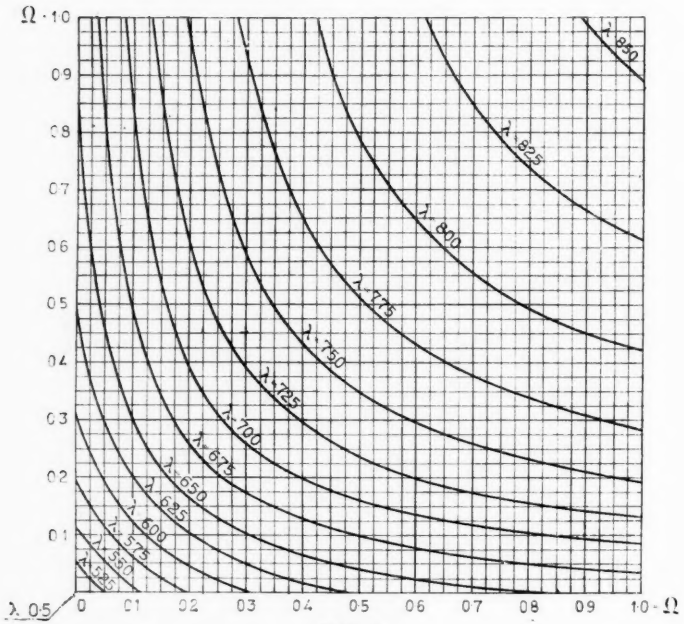

FIG. 5.

EQUIVALENT LENGTH DIAGRAM.
GENERAL CASE.

With aid of this sign convention we now may compute the twist of the supports at the ends of the strut. The reaction of a positive bending moment causes a positive twist at the right end and a negative twist at the left end. Consequently, if we substitute in equation (9)

$$l = x_r + x_l$$

we get

$$\theta_r = \Phi_r M_r = (x_r + x_1)\,\Omega_r M_r / EI \quad . \quad . \quad . \quad . \quad (19)$$

$$\theta_1 = -\Phi_1 M_1 = -(x_r + x_1)\,\Omega_1 M_1 / EI \quad . \quad . \quad . \quad . \quad (19a)$$

From Fig. 4 we find

$$\theta_r = (dy/dx)_r - \rho \quad . \quad . \quad . \quad . \quad . \quad (20)$$

$$\theta_1 = (dy/dx)_1 - \rho \quad . \quad . \quad . \quad . \quad . \quad (20a)$$

Substituting in equation (20) expressions of dy/dx and ρ as given by equations (18) and (16a) respectively and setting the expression thus obtained into equation (19) we get after having solved for M_r

$$M_r = -(AEI/\Omega_r)\{\,\pi\,(\sin \pi x_r/l)/(x_r + x_1)\,l + (\cos \pi x_r/l - \cos \pi x_1/l)/(x_r + x_1)^2\,\} \quad (21)$$

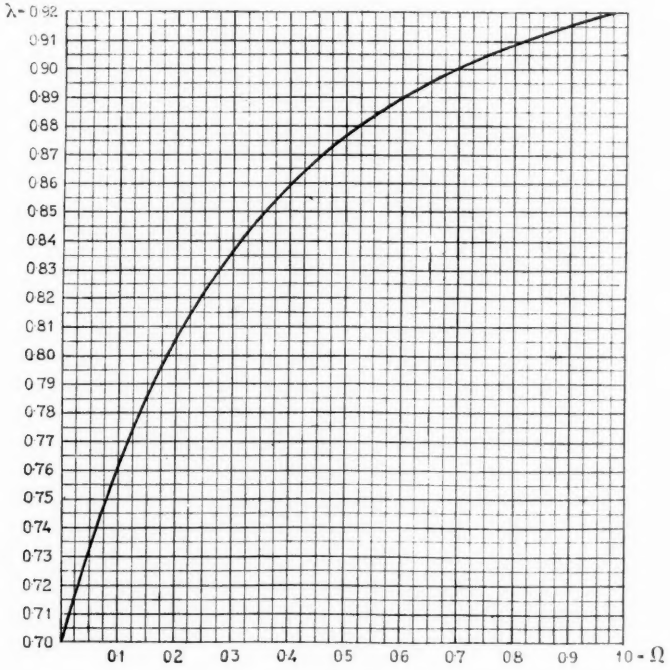

FIG. 6.

EQUIVALENT LENGTH DIAGRAM.

STRUT PIN-JOINTED AT ONE END.

Equating equations (21) and (17) and solving for Ω_r we get

$$\Omega_r = -(\lambda/\pi)\,tg\,\pi x_r/l - (\lambda/\pi)^2\,\{\,1 - (\cos \pi x_1/l)/(\cos \pi x_r/l)\,\} \quad . \quad (22)$$

where

$$\lambda = l/(x_r + x_1) \quad . \quad . \quad . \quad . \quad . \quad (23)$$

Proceeding in a similar way we get for Ω_1

$$\Omega_1 = -(\lambda/\pi)\,tg\,\pi x_1/l - (\lambda/\pi)^2\,\{\,1 - (\cos \pi x_r/l)/(\cos \pi x_1/l)\,\} \quad . \quad (22a)$$

By substituting different values for x_r and x_1 into equations (22) and (22a) corresponding values of Ω_r, Ω_1, and λ can be obtained. These are represented in the diagram of Fig. 5.

The proceedings when calculating the critical load of an elastically encastred strut may now be summarised as follows:—

(1) Compute the R.S.F. for both ends in accordance with the methods evolved in Reference 1.

(2) Take corresponding value of λ from Fig. 5.

(3) Calculate critical load according to equation (14). (Remember that in this equation l denotes the total length of the strut.)

In addition to Figs. 3 and 5 equivalent lengths for two special cases of end constraint have been calculated and represented in diagrams.

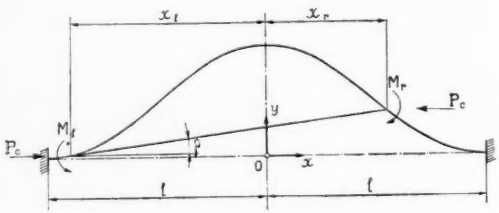

FIG. 7.

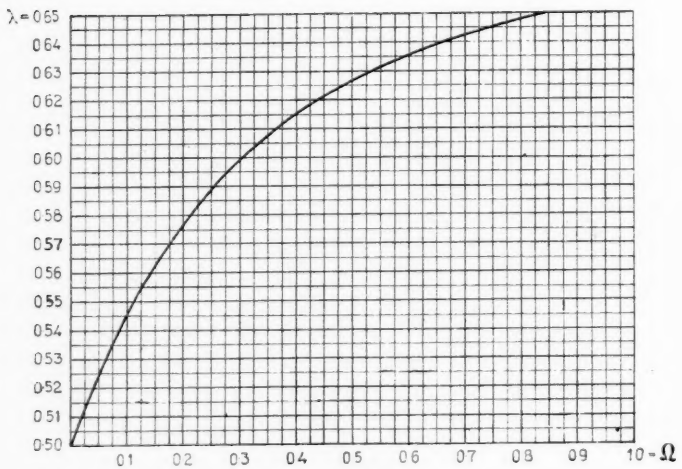

FIG. 8.

EQUIVALENT LENGTH DIAGRAM.
STRUT RIGIDLY ENCASTRED AT ONE END.

First we shall discuss the strut pin-jointed at one end. Let the pin-joint be at the right end. In this case x_r has to be put equal $l/2$. Taking different values for x_l we easily get Ω_l from equation (22*a*). Since values of the equivalent length coefficient λ corresponding to a pin-jointed strut characterised by $\Omega_r=\infty$ are not contained in the diagram of Fig. 5, it was found necessary to plot the diagram of Fig. 6.

The other extreme is represented by a strut rigidly encastred at one end ($\Omega=0$). Let the left end be encastred. In this case the value of x_l corresponding to any given value of x_r may be found by drawing the tangent to the

deflection curve (see Fig. 7). Hereby the condition is fulfilled that the twist at the left end shall equal zero.

With aid of Fig. 7 and results derived heretofore we may write

$$tg\rho = A\,(\cos \pi x_r/l - \cos \pi x_1/l)/(x_r + x_1)$$
$$(dy/dx)_1 = A\,(\pi/l)\,(\sin \pi x_1/l).$$

Since

$$tg\rho = (dy/dx)_1$$

we get

$$(\pi/\lambda)\,(\sin \pi x_1/l) + \cos \pi x_1/l = \cos \pi x_r/l \quad . \quad . \quad . \quad (24)$$

where

$$\lambda = l/(x_r + x_1).$$

By setting different values for x_1 in equation (24) corresponding values of x_r have been calculated. Ω_1 being zero only Ω_r has been computed with aid of equation (22). Results are diagrammatically represented in Fig. 8.

From this last deduction we may understand why it was erroneous to put the equivalent length equal $1.5\,l$ in case of a strut rigidly encastred at one end and pinned at the other. Such equivalent length was only possible for a negative twist at the encastred end. In reality the length is much smaller as it may be calculated by putting $x_r = l/2$ in equation (24):—

$$(\pi/l)\,(\sin \pi x_1/l) + \cos \pi x_1/l = 0 \quad . \quad . \quad . \quad . \quad (25)$$

or

$$tg\pi x_1/l + 1/(\pi x_1/l + \pi/2) = 0 \quad . \quad . \quad . \quad . \quad (25a)$$

The approximate solution is

$$x_1 = 0.93\,l$$

whence

$$\lambda = 0.7$$

and

$$P_c = 2.04\,\pi^2 EI/l^2.$$

§3. Stocky Struts.

Deductions made in §2, of course, are only valid if the limit of elasticity is not surpassed. Their validity may, however, easily be extended, if the behaviour of materials beyond this limit is duly considered. This was done a quarter of a century ago by Professor Kármán (1910)[6] and Professor Southwell (1912),[7] independently. Though results obtained were in good agreement with experiments and perfectly explained the cause of discrepancy between the original Euler theory and reality, they were until now so little known that it seems necessary to outline briefly this extended theory before making use of its results.

If a short, straight strut be centrally loaded by a compressive end load of such magnitude as to cause the uniform stress to exceed the elastic limit, and then slightly deflected, following stress distribution may be expected. On the concave side stress will increase corresponding to a modulus E' having a much lower value than the original Young's modulus E for elastic deflections. This value is represented by the tangent to the stress-strain curve at the point which corresponds to the uniform stress produced by the end load. On the convex side stress will decrease, but only a portion of the elastic part of deflections will be relieved. Hence this decrement corresponds to the original modulus E.

The following calculations have been carried out for a strut of solid rectangular cross-section of width w (see Fig. 9) on the assumption that a plane cross-section at right angles to the plane of bending before strain remains plane after strain.

The sum of the stresses produced by bending must equal zero:—

$$\tfrac{1}{2} \cdot p_c \cdot h_c \cdot w = \tfrac{1}{2}\, p_t \cdot h_t \cdot w \quad . \quad . \quad . \quad . \quad (26)$$

The moment of stresses may be written

$$M = (w/3)\,(p_c h_c^2 + p_t h_t^2) \quad . \quad . \quad . \quad . \quad (27)$$

[6] *Cf.* Reference 4.
[7] *Cf.* Reference 5.

Denoting the radius of curvature of the neutral axis by ρ we may write:—

$$p_c = E' h_c / \rho \quad . \quad . \quad . \quad . \quad . \quad (28)$$

$$p_t = E h_t / \rho \quad . \quad . \quad . \quad . \quad . \quad (28a)$$

From the theory of bending it is known that

$$M / EI = 1 / \rho \cong d^2 y / dx^2 \quad . \quad . \quad . \quad . \quad (29)$$

From equation (26), (28) and (28a) we get

$$E' h_c^2 = E h_t^2.$$

With

$$h = h_c + h_t$$

we may write after several transformations

$$h_c = h \sqrt{E} / (\sqrt{E} + \sqrt{E'}) \quad . \quad . \quad . \quad . \quad (30)$$

and

$$h_t = h \sqrt{E'} / (\sqrt{E} + \sqrt{E'}) \quad . \quad . \quad . \quad . \quad (30a)$$

On substitution of equations (28), (28a) and (30), (30a) into equation (27) we get

$$M = (E' h_c^3 + E h_t^3) w / 3 \rho$$
$$= (w h^3 / 3) \{ E E' / (\sqrt{E} + \sqrt{E'})^2 \} (1 / \rho).$$

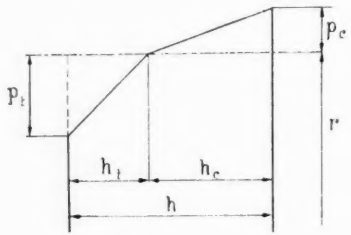

FIG. 9.

Hence

$$1 / \rho = M / \{ E E' / (\sqrt{E} + \sqrt{E'})^2 \} (w h^3 / 3).$$

If we compare this equation with equation (29) and with the expression

$$I = w h^3 / 12,$$

we can state that in case of an initial uniform stress above the limit of elasticity the equation for deflections may be expressed by

$$d^2 y / dx^2 = M / \tau E I \quad . \quad . \quad . \quad . \quad . \quad (31)$$

where

$$\tau = 4 E' / (\sqrt{E} + \sqrt{E'})^2 \quad . \quad . \quad . \quad . \quad (31a)$$

The only difference between the commonly used equation and equation (31) consists in having set in τE for E; this is a consequence of the decrement of the modulus of the material. Results obtained under § 2 may, therefore, be used also for stocky struts after having determined the value of τE. This always is a mean value between E and E' and how it has to be computed depends upon the shape of the cross-section. For solid rectangular cross-section the rule is given by equation (31a); for other cross-sections it can be determined in a similar way. The calculation of τ may, therefore, easily be carried out, if the compressive stress-strain diagram of the material is known. It should, however, be remembered that the behaviour of the material when strained beyond its elastic limit, depends a great measure upon its previous history, as emphasised by Professor Southwell.

It may be mentioned that above results have been computed in the same way as was first done by Professor Kármán. Professor Southwell expressed the

results of his calculations, related to the same subject, by saying that the length of a strut which can sustain a given average intensity of loading is reduced, as a consequence of elastic breakdown, in the ratio

$$2/(1+\sqrt{E/E'}) \quad . \quad . \quad . \quad . \quad . \quad . \quad (32)$$

This result, of course, is the same as obtained by our deduction, the expression on the right hand side of equation (31*a*) being the square of the ratio given by equation (32). For our purposes, however, the first mentioned method is more convenient; we allow for end constraint by reducing the length of the strut with aid of the coefficient λ and for elastic breakdown by reducing the modulus of elasticity with aid of the coefficient τ.

For design purposes we may proceed as follows. From the stress-strain diagram of the material the value of τ corresponding to any given value p of the intensity of end compression may be calculated. The expression for the critical load may be written

$$P_e = \pi^2 \tau E I / l^2 \quad . \quad . \quad . \quad . \quad . \quad (33)$$

Dividing by the cross-sectional area and substituting the expression for the radius of gyration we get

$$p_e = \pi^2 \tau E / (l/k)^2 \quad . \quad . \quad . \quad . \quad . \quad (33a)$$

Substituting in above equation values of τ corresponding to any given value p, as calculated above, corresponding values of l/k are obtained. The graphical representation of values thus computed is a diagram giving the intensity of critical end load as a function of the slenderness ratio l/k. This diagram, of course, retains its validity, if in case of elastic encastrement the slenderness ratio is computed with aid of the equivalent length λl instead of l.

It may be mentioned, that the p_e against l/k diagram is the same for every strut having the same Young's modulus, as long as the value of p_e is below the limit of elasticity. For higher values, however, different diagrams are obtained for every special material and cross-section. The effect of this latter has also been investigated and was found negligible by Professor Kármán in case of I girders and by Professor Southwell in case of solid and hollow circular sections. Professor Southwell stated in his paper on "The Strength of Struts"[8]: "That the employment of equation (32)[9] will not introduce any great inaccuracy in case of solid circular or thin-walled tubular sections, but there is a sensible difference in the case of short struts, therefore any new type of section ought to receive separate treatment."

In consequence p_e against l/k diagrams experimentally found for rectangular struts may also be used for computing tubular struts.

For any further detail reference should be made to the literature quoted in the list of references.

§4. Initially Curved Struts.

In §1 the British view concerning failure of struts has briefly been outlined. According to that maximum fibre stress due to compression and simultaneous bending caused by unavoidable eccentricity of loading, initial curvature of the centre line, etc., is to be calculated. The effect of all these imperfections may approximately be represented by an equivalent eccentricity of loading or a hypothetical initial curvature of the strut. The former method was adopted by Professor Smith and Professor Southwell, the latter by Professor Perry and Professor Robertson.

A deduction of Perry's formula may be found in Messrs. Pippard and Pritchard's "Aeroplane Structures."[10] Below it will be shown that a similar formula may be derived for a strut rigidly encastred at both ends.

[8] *Cf.* Reference 5.
[9] This figure refers to the present paper.
[10] *Cf.* Reference 3, p. 92 *et seq.*

Assuming an initial curvature of the following shape

$$y_o = c_o (\cos \pi x/l + 1) \quad . \quad . \quad . \quad . \quad . \quad (34)$$

we get the following equation for the deflected strut (see Fig. 10):—

$$EId^2y/dx^2 = -P \{ y + c_o (\cos \pi x/l + 1) + M_e/P \} .$$

The solution is

$$y = A \sin \mu x + B \cos \mu x + \{ c_o/(v-1) \} \cos \pi x/l - c_o - M_e/P$$

where

$$\mu = \sqrt{(P/EI)}$$

and

$$v = \pi^2/\mu^2 l^2 = \pi^2 EI/l^2 P = P_e/P.$$

The first differential coefficient is

$$dy/dx = \mu \{ A \cos \mu x - B \sin \mu x \} - (\pi/l) \{ c_o/(v-1) \} \sin \pi x/l.$$

When

$$x = \pm l, \; dy/dx = 0 \text{ and } A = B = 0.$$

When

$$x = \pm l, \; y = 0,$$

whence

$$M_e = -Pc_o v/(v-1) = -Pc_o P_e/(P_e - P).$$

Therefore we may write

$$y = \{ P/(P_e - P) \} c_o (\cos \pi x/l + 1) \quad . \quad . \quad . \quad (35)$$

where

$$P_e = \pi^2 EI/l^2.$$

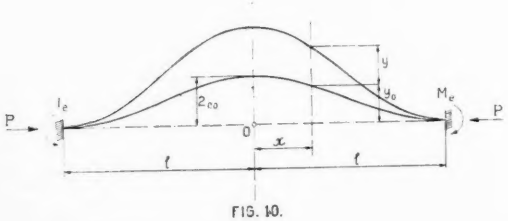

FIG. 10.

P_e is the critical load of a rigidly encastred strut as calculated in § 2. Consequently we can state that Perry's formula for the pin-jointed strut is valid also for the rigidly encastred strut, if only the critical load of the rigidly encastred strut is substituted for P_e and if the initial curvature is assumed in accordance with equation (34).

According to equation (35) we may obtain deflection and slope of an initially curved strut under any given end load by multiplying initial deflection and slope respectively by a factor which depends upon the magnitudes of end load and critical load, but which is a constant for every value of x. If we now regard a portion $x_r + x_1$ of the total length $2l$, initially curved according to the form of that portion of the rigidly encastred strut which extends from $-x_1$ to $+x_r$, the factor by which initial deflection and slope as measured from the new base line $x_1 - x_r$ are to be multiplied for getting deflection and slope under an end load, will remain unaltered.

This may be seen from Fig. 11 where deflections of the rigidly encastred strut are denoted by y, deflections of the $x_1 + x_r$ strut, as measured from the new base line, by η. Values referring to initial curvature have been marked with suffix o. With these notations we may write:—

$$\eta + \eta_o = \{ (1+k) y_o - (1+k) d - (x_1 - x) tg (1+k) \rho_o \} \cos (1+k) \rho_o$$

$$\eta_o = \{ y_o - d - (x_1 - x) tg \rho_o \} \cos \rho_o.$$

In all our previous deductions we supposed that deflections were small. Consequently ρ_o is also small and we may put

$$tg\rho_o = \rho_o,\ tg\,(1+k)\,\rho_o = (1+k)\,\rho_o,$$
$$\cos\rho_o = 1,\ \cos\,(1+k)\,\rho_o = 1.$$

Hence

$$(\eta+\eta_o)/\eta_o = (1+k)$$

and

$$\eta/\eta_o = k = y/y_o,$$

what was to be demonstrated.

Since the shape of the neutral axis of the initially curved strut as expressed by equation (35) is the same as it was found in equation (7) for the initially straight strut under its critical load, the portion $x_r + x_l$ of the total length $2l$ may be considered as the length of an elastically encastred strut, similarly as it was done in § 2. The only difference between both equations is that a definite constant has been substituted for the arbitrary one, demonstrating that in case of the slightest initial curvature the strut cannot remain straight, if a compressive load is applied at its ends.

The agreement of both equations indicates that the values of the R.S.F. corresponding to the lengths x_l and x_r are the same as found under § 2. We can state, therefore, that an elastically encastred strut of length $x_r + x_l$ which was initially curved according to the corresponding portion of the neutral axis of the strut shown in Fig. 11 will retain the shape of its centre line when further deflected by a compressive end load.

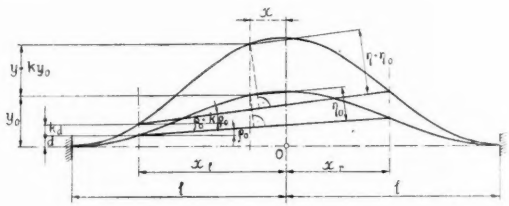

FIG. 11.

The factor by which initial deflections are to be multiplied is given by

$$f = P/(P_e - P)$$

where P_e denotes the critical load of the rigidly encastred strut. It is, of course, more convenient again to introduce the equivalent length and to write

$$P_e = \pi^2 EI/(\lambda l)^2 \quad . \quad . \quad . \quad . \quad . \quad (14)$$

where λ is the equivalent length coefficient computed under § 2.

In consequence when a strut is curved, or if the effect of imperfections of material, workmanship, and loading may be put equal an initial curvature of a shape given above, the greatest initial deflection being c, the greatest deflection under a compressive end load P may be written

$$y = cP/(P_e - P)$$

if y measured from the initial curve and

$$y = cP_e/(P_e - P)$$

if y measured from the line of action of the load. Hence the greatest stress developed is

$$p = c\,\{\,P_e/(P_e - P)\,\}\,Pa/I + P/A \quad . \quad . \quad . \quad (36)$$

where A is the area, I the moment of inertia of the cross-section, a the distance of the most stressed compressive fibre from the neutral axis and P_e the critical load of the elastically encastred strut according to equation (14).

It may be remembered that these results have been obtained by assuming a

quite definite shape for the hypothetical initial curvature. Though the exact form of the centre line is not of great importance for the stress developed, mention must not be omitted that a systematic error seems to have been introduced into our calculations by taking different shapes of initial curvature for different grades of encastrement; obviously we should have got greater deflections for the rigidly encastred strut, if we had assumed an initial curvature like that taken for the pin-jointed strut. The difference, however, cannot be great; we know that in case of pin-jointed struts a constant eccentricity gives only about 1.2 times[11] greater deflections than the trigonometric law chosen by us.

This conclusion would hold, if causes of failure were the same for every grade of encastrement. Yet this is not the case. Initial crookedness, eccentricity of bore of tubular struts, and eccentricity of attachment may be regarded the major causes of departure from the ideal straight strut. The effect of initial crookedness has above been investigated; the effect of eccentricity of loading may be examined as follows:—[12]

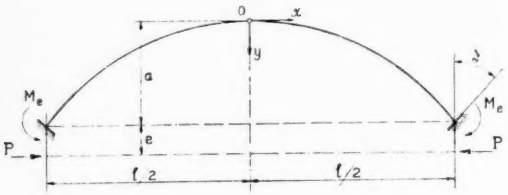

FIG. 12.

With notations of Fig. 12 we may write

$$d^2y/dx^2 = \mu^2 (a + e - y + M_e/P) \quad . \quad . \quad . \quad . \quad (37)$$

where again

$$\mu = \sqrt{(P/EI)}.$$

The solution is

$$y = (a + e + M_e/P)(1 - \cos \mu x) \quad . \quad . \quad . \quad . \quad (38)$$

what may easily be proved by substituting the value of y given by equation (38) into equation (37); thereby an identity will be obtained. The first differential coefficient is

$$dy/dx = \mu (a + e + M_e/P) \sin \mu x.$$

When

$$x = 0, \; y = 0 \text{ and } dy/dx = 0.$$

When

$$x = \pm l/2, \; y = a,$$
$$a = (a + e + M_e/P)(1 - \cos \mu l/2).$$

Hence

$$a = (e + M_e/P)(\sec \mu l/2 - 1) \quad . \quad . \quad . \quad . \quad (39)$$

The value of M_e/P may be computed by putting

$$\theta = -\Phi M_e.$$

Since this must equal the slope of the neutral axis at the end of the strut we may write

$$\mu (a + e + M_e/P) \sin \mu l/2 = -\Phi M_e.$$

Hence

$$M_e/P = -(a + e)(\mu \sin \mu l/2)/(\mu \sin \mu l/2 + \Phi P) \quad . \quad . \quad (40)$$

In case of a pin-jointed strut we have to put $\Phi = \infty$. Consequently $M_e/P = 0$

[11] *Cf.* Reference 6, p. 56.

[12] A similar deduction for pin-jointed struts may be found in Reference 3, p. 86.

and $$a = e\ (\sec \mu l/2 - 1) \quad . \quad . \quad . \quad . \quad . \quad (41)$$

in agreement with results quoted in text-books.

In case of a finite value of Φ we find

$$-M_e/P = k\ (a + e)$$

where k is a fraction. Maximum deflection is given by

$$a = e\ \{\ (\sec \mu l/2)/(1 - k + k \sec \mu l/2) - 1\ \} \quad . \quad . \quad (42)$$

With $\Phi = 0$, *i.e.*, rigid encastrement, we get $k = 1$ and consequently

$$a = 0 \text{ and } M/P = -e.$$

In this case the strut suffers no bending moments. It may be seen, therefore, that the effect of eccentricity on maximum fibre stress is much less for elastically encastred struts than in case of pin-jointed ends. It vanishes for rigid encastrement. Since with the method adopted in this paragraph the hypothetical curvature represents the effects of both initial crookedness and eccentricity of loading, we are authorised to assume with increasing stiffness of encastrement a gradually lesser effective shape for the initial curvature.

Our assumption concerning the shape of initial curvature is further supported by the effect of the increased stiffness of ends of struts which are members of a framework. Since these are attached to other members joined at the same node by relatively long welds or riveted fishplates, cross-section and moment of inertia at the end are much greater than at the unreinforced middle portion. Investigations have shown[13] that this fact is best accounted for by assuming the moment of inertia to increase according to a hyperbolic law. For simplicity, however, in the following considerations we shall regard the ends as perfectly rigid.

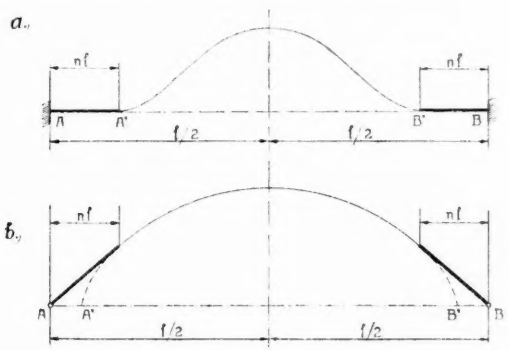

FIG. 13.

From Fig. 13 it may be readily seen that the influence of rigid ends on the equivalent length depends a great deal upon end constraint. Fig. 13*a* may be regarded as a rigidly encastred strut having an effective length

$$A'B' = l - 2nl.$$

Its equivalent length is, therefore, given by

$$\lambda l = (\tfrac{1}{2})\ (1 - 2n)\ l.$$

Fig. 13*b* represents a pin-jointed strut. Equivalent length may be computed from the ratio

$$A'B'/AB = \lambda.$$

Values calculated in Reference 4 by Professor Kármán[14] are compared in the following table with corresponding values for rigid encastrement.

[13] *Cf.* Reference **1**, §3.
[14] *Cf.* Reference **4**, p. 6.

EFFECT OF RIGID END.

n ... ... =	0.02	0.05	0.10	0.15
λ (pin-jointed strut) ... ... =	0.9996	0.9992	0.994	0.978
2λ (rigidly encastred strut) ... =	0.96	0.90	0.80	0.70

In reality the difference is smaller, since ends may not be regarded as perfectly rigid. From all these calculations, however, it must be clear that there are too many factors influencing phenomena as to allow for each separately. Our assumption for the shape of the hypothetical initial curvature may, therefore, be regarded as a compromise. The accuracy attained may only be checked by experiment.

For the calculation of maximum fibre stress according to equation (36) we may put

$$c = \text{length}/500 + \text{internal diameter}/33 \quad . \quad . \quad . \quad (43)$$

in case of commercial tubes. In this equation c appears 1.2 times the value of δ as used in the Smith-Southwell formula. Alternatively we may write equation (36) in the form[15]

$$p = \{ p_y + (\eta + 1) p_c \} / 2 - \sqrt{ \{ [p_y + (\eta + 1) p_c]^2 / 4 - p_y p_c \} } \quad . \quad (44)$$

where p_y is the yield stress in compression, p_c the critical stress as calculated from the critical load given by equation (14), p the intensity of end loading which will cause the fibre stress to reach the yield point, and

$$\eta = ca/k^2.$$

In this last formula c denotes the maximum initial deflection, a the distance of the most stressed compressive fibre from the neutral axis and k the radius of gyration.

Since as a result of his tests Professor Robertson suggested the same value for η in both cases when ends of the strut are pin-jointed and when rigidly encastred, obviously the same value may be retained for the intermediate cases of elastic encastrement. The value is given by

$\eta = 0.003\ l/k$ for ductile materials and
$\eta = 0.015\ l/k$ for brittle materials.

It is customary to disregard the decrement of the modulus of the material in case of stocky struts when calculating p_c for substitution into equation (44). It can, however, easily be taken into account with the aid of considerations outlined in §3. The approximation thereby attained is, however, somewhat less good than in the case of the critical load, since the assumption of two linear laws for the stress distribution holds strictly only for infinitesimal deflections. In case of deflections of such magnitude as to cause failure, on the compression side of the neutral axis stress will increase from the value of the intensity p of end loading to the yield stress p_y according to a curved line and we have, therefore, to calculate τ for some mean value of stress between p and p_y; it would be erroneous to take a value of τ corresponding to the critical stress of the strut, as calculated in §2.

§5. FAILURE OF FRAMEWORK MEMBERS UNDER END COMPRESSION.

When the strength of an actual framework, *e.g.*, a side panel of a welded steel tube fuselage is to be checked, the following method of calculation is suggested. After having computed end loads, strength of members in compression should first be checked on the assumption of pin-jointed ends throughout. The effect of elastic encastrement should only be taken into account for struts which would fail when pin-jointed.

The relative stiffness factor of the ends of struts in question may be calculated as follows. The framework should be divided into groups of members. Members of the same group are regarded as rigidly connected with one another and between

[15] *Cf.* Reference 3, p. 93.

members of different groups pin-joints are assumed. Division is to be made in a way as to connect every compression member which would fail when pin-jointed with the greatest possible number of members in tension or slight compression. No group must have more than one overstrained compression member and no member must be contained in more than one group. For computing the R.S.F. for the ends of such overstrained struts only members which are contained in the same group should be taken into account.

It may be noted that for different conditions of loading the same framework may be divided into different groups, if necessary.

When we regard one group separately the R.S.F. may be computed without difficulty on the basis of methods evolved in Reference 1. When elastic encastrement is to be taken into account for a great number of members the framework will be divided in so many groups that most members will be assumed pin-jointed at one end. For these the influence of end load on the value of the stiffness factor f[16] may be easily taken into account. Since f was defined by

$$\theta = Ml/fEI$$

where l is the length, E Young's modulus, I the moment of inertia of the member, M the external moment acting on the member at its end and θ the

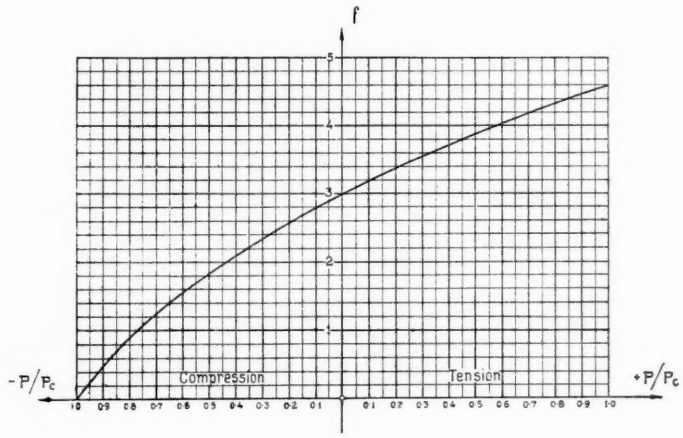

FIG. 14.

twist at the same end due to M, it is obvious that f may be connected with Berry functions by the following equations:—

$$f = 3/\phi\ (\alpha) \text{ in case of compression and}$$
$$f = 3/\Phi\ (\alpha) \text{ in case of tension.}$$

For convenience values thus calculated have been represented in Fig. 14.

§6. Summary.

The method suggested for calculating failure of elastically encastred struts may be summarised as follows:—

(1) In case of frameworks the relative stiffness factor (R.S.F.) of the nodes to which the ends of the strut are attached should be calculated as outlined in Reference 1, §12. The effect of end loads, however, generally may not be disregarded.

[16] *Cf.* Reference 1, §8.

(2) The equivalent length λl of the strut should be determined with aid of the factor λ plotted against the R.S.F. in the diagrams of

Fig. 3 in the symmetrical case;
Fig. 5 in the general case;
Fig. 6 if the strut is pin-jointed at one end; and
Fig. 8 if rigidly encastred at one end.

(3) The reduced modulus of elasticity τE corresponding to any intensity of end loading p may be computed for rectangular, solid circular, thin-walled tubular and I sections from the equation

$$\tau = 4E'/(\sqrt{E} + \sqrt{E'})^2 \quad . \quad . \quad . \quad . \quad (31a)$$

(4) If values of E' in function of the stress are not obtainable, *i.e.*, a compressive stress strain diagram of the material is not at our disposal, a strut diagram in which the critical intensity of loading p_c is plotted against the slenderness ratio may also be used, if available.

(5) The critical load of a strut may be computed from the following equation :—

$$P_c = \pi^2 \tau E I/(\lambda l)^2 \quad . \quad . \quad . \quad . \quad (45)$$

Alternatively the intensity of the critical load p_c may be taken from the diagram mentioned under (4) for the equivalent slenderness ratio

$$\lambda l/k.$$

(6) The greatest compressive stress developed in a strut is given by

$$p = \{ P_c/(P_c - P) \}\, caP/I + P/A \quad . \quad . \quad . \quad (36)$$

where the value of c may be put

$$c = \text{length}/500 + \text{internal diameter}/33 \quad . \quad . \quad . \quad (43)$$

In equation (28) P_c may be calculated according to (5) or alternatively (4) it may be put

$$P_c = p_c A.$$

(7) The intensity of end loading which will cause the fibre stress to reach the yield point is given by

$$p = \{ p_y + (\eta + 1)\, p_c \}/2 - \sqrt{\{ [p_y + (\eta + 1)\, p_c]^2/4 - p_y p_c \}} \quad . \quad (44)$$

where η may be put

$\eta = 0.003\, l/k$ for ductile materials.
$\eta = 0.015\, l/k$ for brittle materials.

p_c may be taken from the diagram mentioned under (4) or it may be calculated from the critical load (according to (5)) with aid of equation

$$p_c = P_c/A.$$

(8) For stressing compression members of frameworks the proceedings outlined under §5 should be followed.

(9) Struts which are not contained in a framework may be treated in similar manner if the stiffness of encastrement can be determined by calculation or experiment.

Appendix.

List of References.

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2. "The Strength of Struts: A Review of Progress Made in Theory and Experiment during the War," by R. V. Southwell. (A.R.C. R. & M., No. 918, London, 1924.)
3. "Aeroplane Structures," by A. J. S. Pippard and J. L. Pritchard. (Longmans, Green & Co., London, 1935.)
4. "Untersuchungen über Knickfestigkeit," by Th. von Kármán. (Mitteilungen über Forschungsarbeiten, Heft. 81, V.D.I., Berlin, 1910.)
5. "The Strength of Struts," by R. V. Southwell. (Engineering, August 23, 1912.)
6. "The Stresses in Aeroplane Structures," by H. B. Howard. (Sir Isaac Pitman & Sons Ltd., London, 1933.)

THEORY OF THE SLAT IN A TWO-DIMENSIONAL FLOW

By Prof. V. V. Golubev.

Text Translated from the Russian and Edited[1] by
J. R. Crean, B.Sc. (Eng.).

Transactions of the Central Aero-Hydrodynamical Institute, Moscow, No. 147 (*February*, 1933). "*Investigations into the Theory of the Slotted Wing.*" *Part I.*

Part I.

Introduction; Some Fundamental Formulæ.

1. The theory of the aerofoil has now been studied to such an extent that, from this province, it is hardly possible to expect further material improvement in its aerodynamical qualities: profiles differing but little from an inverse of a parabola (Joukovski profile) would appear to be the theoretical ideal. Subsequent important progress in that respect may be sought only in another direction, viz., in the application of a series of supplementary contrivances having a marked influence on the properties of the flow around the aerofoil. Here we are referring to such devices as the sucking away of the boundary layer (Absaugeflügel), or the insertion of appliances on the aerofoil itself. Nevertheless, up to the present, only one of the very earliest attempts in this direction, namely, the slotted wing, has developed sufficiently to be in any way widely adopted in contemporary aircraft construction.

Yet in spite of the fact that slotted wings have already been known for more than ten years and have received an adequate diffusion throughout practice, their theory is still in a very rudimentary state. In a literature containing considerable experimental material there are to be found very few works devoted to the theory. One can point to only one fundamental theoretical work—that of S. A. Tchaplygin[2]—wherein is given a very detailed theory for one particular type of slotted wing, based on the assumption that the wing works under the conditions of an entirely streamline flow in a perfect fluid. In addition to this, there exists a number of works in foreign literature which contain certain theoretical considerations on slotted wings. In the first place, we must mention that of Lachmann,[3] in which is investigated the structure of the flow around such a wing; further, that of Betz,[4] where a wing with a forward aerofoil is examined as a particular case of the biplane; and finally, a series of theoretical observations by Prandtl, Betz, Klemperer, and others. But in none of the works enumerated is there to be found a complete theory that takes into account the viscosity of the air, which, as it seems, must play a vital part in all phenomena connected with improvement of the action of the wing.

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[1] The mathematical expressions in the present abridged version occasionally differ in points of detail from those in the original Russian text owing to the presence of algebraic errors in the latter.

[2] "Schematic Theory of the Slotted Wing of an Aeroplane." (Nautchno-tekhnicheski Vestnik, Nos. 4-5, 1921).

[3] "Die Strömungsvorgänge an einem Profil mit Vorgelagertem Hilfsflügel." (Z.F.M. Jahrgang 14, 1923).

[4] "Die Wirkungsweise von unterteilten Flugprofilen." (Berichte und Abh. der Wissenschaften Gesellschaft für Luftfahrt, Jan., 1922).

The object of the present paper is to give as complete as possible a theory in the simplest case, viz., where we have a wing with a forward aerofoil (slat). The influence of the viscosity of the air will be allowed for by a systematic application of Prandtl's boundary layer theory.

2. Experimental data indicate that the effect of a slat is to cause an increase in the angle of attack that marks the limit of streamline flow over an aerofoil. Consequently the theoretical investigation of the action of a slat amounts to the solution of the two following fundamental problems:—

(a) Determination of the conditions under which begins the breakaway of the streamlines from the upper surface of an aerofoil.

(b) Determination of the influence of the slat on those conditions.

The question of the breakaway of streamlines is solved in contemporary aerodynamics from two different points of view. Attempts to reach a solution based on application of the theory of a perfect fluid gave rise to a method which has been treated for very simple cases by Kirchoff, Rayleigh, Michel, and Joukovski,[5] and later assumed a considerably improved form in the methods of Levi-Civita and Villat.[6] As regards the flow around crinoline contours it has, up to the present, proved unreliable only in a very limited number of instances. On the subject of such contours, special mention must be made of A. I. Nekrassov's investigation of the flow around an arc of a circle,[7] and that of N. S. Arjanikov for an arc of a parabola.[8] Unfortunately this method, which presents very great analytical difficulties, has not so far been applied to the determination of the points of breakaway of the streamlines on contours of the shape of an aerofoil profile.

The other method, based on application of the boundary layer theory and developed by Prandtl, Blasius, von Kármán, Polhausen, and others,[9] likewise affords great analytical difficulties and, as yet, has been applied successfully only to the cases of a thin plate and a circular cylinder. Subsequently we shall see how the problem of the breakaway of the streamlines from the surface of an aerofoil can be solved approximately by means of it.

The second fundamental question, viz., that concerned with the influence of a slat on the conditions of smooth flow over an aerofoil, can also be solved in various ways. In its general form, it presents a particular case in the theory of the biplane and would seem to involve elliptic functions.

A special case where the slat and main aerofoil are arcs of the same circle, has been completely solved by S. A. Tchaplygin.[10] However, in our own, the task may be simplified due to the fact that the dimensions of the auxiliary aerofoil are small as compared with those of the main aerofoil. Accordingly, as a first approximation, the slat may be replaced by a single vortex, permanently fixed relative to the aerofoil, and becoming therefore a member of the bound vortex system of the slotted wing.

At first sight it may seem that such a project would give results that were extremely crude and therefore of little value; but it must not be forgotten that at the root of the whole of Prandtl's wing theory there lies a still more arbitrary assumption, viz., that the entire vortex system of a wing is replaceable by a single vortex of variable circulation; nevertheless, the integral results for the magnitudes of the lift and the drag, the downwash, etc., prove entirely satisfactory, and it is only for such questions as the determination of the centre of pressure, the distribution of the velocities around the wing, that the theory proves inadequate and has to be supplemented by the application, for example, of the theory of two-dimensional flow to individual elements of the wing.

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[5] "On a Modification of Kirchoff's Method." Collected Works. Vol. II, No. 2.
[6] Villat. "Aperçu Théorique sur la Résistance des Fluides."
[7] Bulletin of the Ivanovo-Voznesensk Polytechnic Institute, 1924.
[8] Matematicheski Sbornik, 1928.
[9] L. Prandtl. "Vier Abhandlungen zur Hydro-und Aerodynamik," 1927.
[10] See §1. Reference (2).

So we shall be considering the flow around an aerofoil having a vortex permanently fixed in position relative to it.

Parts II and III of this paper are devoted, respectively, to the fundamental questions (*a*) and (*b*) mentioned at the commencement of this section.

3. We shall commence with an examination of the general problem of the behaviour of an aerofoil in a superimposed translational flow in the case where around the aerofoil there exists a system of vortices fixed in position with respect to it.

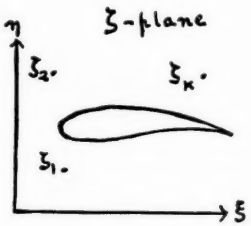

FIG. 1.

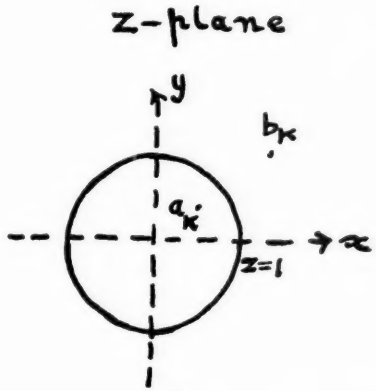

FIG. 2.

Suppose that on the $\zeta\,(=\xi+i\eta)$-plane (Fig. 1) we have an aerofoil profile around which there is a system of vortices, I_K whose axes are situated at the points ζ_K. Let us represent the ζ-plane conformally on a $z\,(=x+iy)$ plane so that the part of the former exterior to the profile will correspond to the part of the latter exterior to the circle $|z|=1$ (Fig. 2). Then the axes of the vortices will correspond to certain points b_K in the z-plane, the sharp trailing edge to the point $z=1$, and the point $\zeta=\infty$ to the point $z=\infty$. The derivative of the potential function of the flow against the cylinder is then obtained in the form :—

$$dw/dz = V_\infty e^{-\theta i}\,(1-e^{2\theta i}/z^2) + (\Gamma/2\pi i)\,(1/z) + \Sigma\,(1/2\pi i)\,\{\,I_K/(z-b_K)\,\} - \Sigma\,(1/2\pi i)\,\{\,I_K/(z-a_K)\,\} \quad . \quad . \quad . \quad . \quad (1)$$

where V_∞ = velocity at infinity of the translational flow.

θ = the angle made by its direction with the x-axis.

Γ = the fundamental circulation around the aerofoil.

b_K and a_K = positions of vortex axes; moreover $b_K = 1/\bar{a}_K$ where $\bar{a}_K$ is the complex conjugate of a_K, so that the points b_K and a_K lie on the same straight line passing through the origin.

Let $\zeta=\chi\,(z)$ be the function giving the correspondence between the two planes; outside the circle $|z|=1$, we have for $\chi\,(z)$ the expansion :—

$$\zeta = az + b + c/z + d/z^2 + \ldots$$

Denoting by X and Y the components of the lift in the ζ-plane, we obtain by the Tchaplygin-Blasius formula

$$Y + iX = -(\rho/2)\int_C (dw/dz)^2\,(dz/d\zeta)\,dz$$

where c is any contour enclosing the circle $|z|=1$ but excluding the points b_K.

Whence, substituting for dw/dz from (1), we have:—

$$Y+iX=-(\rho/2)\int_C \{ V_\infty e^{-\theta i}(1-e^{2\theta i}/z^2)+(\Gamma/2\pi i)(1/z)+(1/2\pi i)\Sigma[I_K/(z-b_K)] - (1/2\pi i)\Sigma[I_K/(z-a_K)]\}^2\{dz/\chi'(z)\} \quad . \quad . \quad . \quad (2)$$

For the evaluation of the integral we apply the theory of residues. Since on and exterior to the contour, $\chi'(z)$ is everywhere finite, then the points $z=0$, $z=a_K \ldots$, will be the poles of the integrand within C. We shall find the residues with respect to all these poles.

Expanding (2):—

$$\begin{aligned} Y+iX=-(\rho/2)\int_C \{ & V^2_\infty e^{-2\theta i}(1-e^{2\theta i}/z^2)^2+[\Gamma^2/(2\pi i)^2](1/z^2) \\ & +[(1/2\pi i)^2]\Sigma[I^2_K/(z-b_K)^2]+[1/(2\pi i)^2]\Sigma[I^2_K/(z-a_K)^2] \\ & +2V_\infty e^{-\theta i}(1-e^{2\theta i}/z^2)(\Gamma/2\pi i)(1/z)+2V_\infty e^{-\theta i}(1-e^{2\theta i}/z^2)(1/2\pi i)\Sigma[I_K/(z-b_K)] \\ & -2V_\infty e^{-\theta i}(1-e^{2\theta i}/z^2)(1/2\pi i)\Sigma[I_K/(z-a_K)]+[2\Gamma/(2\pi i)^2]\Sigma[I_K/z(z-b_K)] \\ & -[2\Gamma/(2\pi i)^2]\Sigma[I_K/z(z-a_K)]+[2/(2\pi i)^2]\Sigma[I_K I_E/(z-b_K)(z-b_E)] \\ & +[2/(2\pi i)^2]\Sigma[I_K I_E/(z-a_K)(z-a_E)] \\ & -[2/(2\pi i)^2]\sum_K\sum_E[I_K I_E/(z-b_K)(z-a_E)]\}[dz/\chi'(z)] \quad . \quad . \quad (3) \end{aligned}$$

The evaluation of the integrals in (3) presents a difficulty inasmuch as the behaviour of the function $\chi(z)$ within the circle $|z|=1$ is unknown to us and therefore we cannot directly apply Cauchy's theorem to the interior of the curve C. As regards the behaviour of $\chi(z)$ exterior to the circle, then there $\chi'(z)$ never becomes zero since the function $\chi(z)$ gives a conformal representation of the whole of that part of the z-plane; consequently $1/\chi'(z)$ outside the circle $|z|=1$ is everywhere holomorphic.

Hence it follows that the integrals, the denominators of whose integrands do not contain $(z-b_K)$ may be taken, in lieu of along the circle $|z|=1$, along any curve enclosing that circle. We shall choose as their path of integration a circle C_∞ of infinitely large radius with centre at the origin.

Then

$$\int_{C_\infty}(1-e^{2\theta i}/z^2)^2\{dz/\chi'(z)\}=0;\int_{C_\infty}dz/\{z^2\chi'(z)\}=0;\int_{C_\infty}dz/\{(z-a_K)^2\chi'(z)\}=0;$$

$$\int_{C_\infty}dz/\{(z-a_K)(z-a_E)\chi'(z)\}=0;$$

$$\int_{C_\infty}(1-e^{2\theta i}/z^2)\,dz/\{z\chi'(z)\}=\int_{C_\infty}(dz/z)[1/a+(c/a^2)(1/z^2)+\ldots]=2\pi i(1/a);$$

$$\int_{C_\infty}(1-e^{2\theta i}/z^2)\,dz/\{(z-a_K)\chi'(z)\}=\int_{C_\infty}dz/\{(z-a_K)\chi'(z)\}=2\pi i(1/a);$$

$$\int_{C_\infty}\{dz/z(z-a_K)\chi'(z)\}=0.$$

To evaluate the integrals whose integrands contain $(z-b_K)$ in the denominator we proceed as follows:—Describe around the point b_K a circle C_K of sufficiently small radius for C_K to lie entirely outside C; then

$$\int_{C_K}+\int_C=\int_{C_\infty}$$

since throughout the region bounded by the circles C_∞, C, C_K the integrands are holomorphic.

On applying the same transformations as above, we shall find that the integrals of terms which have in the denominator any of the products $(z-a_E)(z-b_K)$, $z(z-b_K)$, or $(z-b_K)^2$, are, on the circle C_∞ equal to zero; consequently for these integrals we have:—

$$\int_C = -\int_{C_K}$$

Therefore

$$\int_C dz/\{(z-b_K)^2\chi'(z)\} = -\int_{C_K}\{dz/(z-b_K)^2\}(1/\chi'(b_K)$$
$$-[\chi''(b_K)/\chi'^2(b_K)](z-b_K)+\ldots) = 2\pi i[\chi''(b_K)/\chi'^2(b_K)];$$

$$\int_C (1-e^{2\theta i}/z^2)\,dz/\{(z-b_K)\chi'(z)\} = \int_{C_\infty}(1-e^{2\theta i}/z^2)\,dz/\{(z-b_K)\chi'(z)\}$$

$$-\int_{C_K}(1-e^{2\theta i}/z^2)\,dz/\{(z-b_K)\chi'(z)\} = 2\pi i(1/a)-2\pi i(1-e^{2\theta i}/b^2_K)\{1/\chi'(b_K)\};$$

$$\int_C dz/\{z(z-b_K)\chi'(z)\} = -\int_{C_K} dz/\{z(z-b_K)\chi'(z)\} = -2\pi i\,.\,1/\{b_K\chi'(b_K)\};$$

$$\int_C dz/\{(z-b_K)(z-b_E)\chi'(z)\} = -\int_{C_K} dz/\{(z-b_K)(z-b_E)\chi'(z)\}$$

$$-\int_{C_E} dz/\{(z-b_K)(z-b_E)\chi'(z)\} = -2\pi i\,.\,1/\{(b_K-b_E)\chi'(b_K)\}$$
$$-2\pi i\,.\,1/\{(b_E-b_K)\chi'(b_E)\};$$

$$\int_C dz/\{(z-b_K)(z-a_E)\chi'(z)\} = -\int_{C_K} dz/\{(z-b_K)(z-a_E)\chi'(z)\}$$
$$= -2\pi i\,.\,1/\{(b_K-a_E)\chi'(b_K)\}.$$

Upon substitution of the values of all the above integrals, (3) reduces to:—

$$Y+iX = -\rho V_\infty e^{-\theta i}[\Gamma/a-\Sigma I_K(1-e^{2\theta i}/b^2_K)\{1/\chi'(b_K)\}]$$
$$-(\rho/4\pi i)\Sigma\{I^2_K\chi''(b_K)/\chi'^2(b_K)\}+(\rho\Gamma/2\pi i)\Sigma\{I_K/b_K\chi'(b_K)\}$$
$$+(\rho/2\pi i)\Sigma I_K I_E\{1/[(b_K-b_E)\chi'(b_K)]+1/[(b_E-b_K)\chi'(b_E)]\}$$
$$-(\rho/2\pi i)\sum_K\sum_E I_K I_E/\{(b_K-a_E)\chi'(b_K)\} \quad . \quad . \quad . \quad (4)$$

In the case where there are no vortices, I_K, we get Joukovski's formula:—

$$Y+iX = -\rho V_\infty e^{-\theta i}(\Gamma/a) \quad . \quad . \quad . \quad . \quad (5)$$

If there is only a single vortex pair I_1, we have:—

$$Y_1+iX_1$$
$$= -\rho V_\infty e^{-\theta i}[\Gamma/a-I_1(1-e^{2\theta i}/b^2_1)\{1/(\chi'b_1)\}]-(\rho/4\pi i)\{I^2_1\chi''(b_1)/\chi'^2(b_1)\}$$
$$+(\rho\Gamma/2\pi i)\{I_1/b_1\chi'(b_1)\}-(\rho/2\pi i)I^2_1/\{(b_1-a_1)\chi'(b_1)\} \quad . \quad (6)$$

Hence the influence of the vortex pair is manifested in the additional lift:—

$$\Delta Y+i\Delta X = Y_1+iX_1-(Y+iX)$$
$$= \rho I_1[V_\infty e^{-\theta i}(1-e^{2\theta i}/b^2_1)+(\Gamma/2\pi i)(1/b_1)]\{1/\chi'(b_1)\}$$
$$+[i\rho I^2_1\chi''(b_1)]/[4\pi\chi'^2(b_1)]+(i\rho/2\pi)I^2_1/\{(b_1-a_1)\chi'(b_1)\} \quad . \quad (7)$$

But

$$V_\infty e^{-\theta i}(1-e^{2\theta i}/b^2_1)+(\Gamma/2\pi i)(1/b_1) = (dw_0/dz)_{z=b_1}$$

where w_0 is the potential function when no vortices are present and therefore from (7)

$$\Delta Y+i\Delta X = \{\rho I_1/\chi'(b_1)\}(dw_0/dz)_{z=b_1}+[i\rho I^2_1\chi''(b_1)]/[4\pi\chi'^2(b_1)]$$
$$+i\rho I^2_1/[2\pi(b_1-a_1)\chi'(b_1)] \quad . \quad . \quad . \quad . \quad (8)$$

Quite another result is obtained if all the vortices belong to the bound vortex system of the aerofoil, for then, in order to determine the force produced by the flow, it is necessary to take the integral in (3) along a contour enclosing all of them.

In that case, therefore, we may take as the path of integration a circle C_∞ of infinite radius. Applying the relevant transformations already deduced to equation (3) we then get :—

$$\begin{aligned} Y+iX &= -\tfrac{1}{2}\rho\,[V_\infty e^{-\theta i}\,(\Gamma/\pi i)\,(2\pi i/a) \\ &+ (V_\infty e^{-\theta i}/\pi i)\,\Sigma\, I_K\,(2\pi i/a) - (V_\infty e^{-\theta i}/\pi i)\,\Sigma\, I_K\,(2\pi i/a)] \\ &= -\rho V_\infty e^{-\theta i}\,(\Gamma/a) \quad . \quad . \quad . \quad . \quad . \quad (9) \end{aligned}$$

Thus the formula is of exactly the same form as that for no vortices present.

Nevertheless, one must not conclude that the lift here is independent of the vortices added. It is easily shown that the value of the circulation Γ depends upon the magnitudes of the vortices I_K.

For, if the point $z=1$ corresponds to the sharp trailing edge, then by a fundamental hypothesis of Joukovski :—

$$(dw/dz)_{z=1}=0.$$

Consequently we have the equation :—

$$V_\infty e^{-\theta i}\,(1-e^{2\theta i}/1)+\Gamma/2\pi i+(1/2\pi i)\,\Sigma\, I_K/(1-b_K)-(1/2\pi i)\,\Sigma\, I_K/(1-a_K)=0.$$

Whence

$$\Gamma=-4\pi V_\infty \sin\theta+\Sigma\, I_K\,(1/(1-a_K)-1/(1-b_K) \quad . \quad . \quad (10)$$

This is at once seen to give a real value for Γ; for let $a_K=\rho_K e^{\phi_K i}$, then $b_K=(1/\rho_K)\,e^{\phi_K i}$.

Therefore

$$1/(1-a_K)-1/(1-b_K)=(1-\rho^2{}_K)/(1-2\rho_K\cos\phi_K+\rho^2{}_K).$$

Hence

$$\Gamma=-4\pi V_\infty \sin\theta+\Sigma\, I_K\,(1-\rho^2{}_K)/(1-2\rho_K\cos\phi_K+\rho^2{}_K) \quad . \quad . \quad (11)$$

Since in the absence of vortices :—

$$\Gamma=\Gamma_0=-4\pi V_\infty \sin\theta.$$

Then

$$\Delta\Gamma=\Gamma-\Gamma_0=\Sigma\, I_K\,(1-\rho^2{}_K)/(1-2\rho_K\cos\phi_K+\rho^2{}_K) \quad . \quad . \quad (12)$$

As $\rho_K<1$, the expression

$$(1-\rho^2{}_K)/(1-2\rho_K\cos\phi_K+\rho^2{}_K)$$

is always positive. Thus we have the following result :—If around an aerofoil there are vortices then its circulation alters; moreover, each vortex possessing a circulation of the same (opposite) sense as (to) that of the original circulation about the aerofoil increases (decreases) the latter.

Hence, combining this with (9), we see that if in the vicinity of an aerofoil there is a bound vortex with a circulation of the same sense as that of the aerofoil, then the total lift acting on both vortex and aerofoil is greater than the lift on the aerofoil in the absence of the vortex; if, on the other hand, the circulation of the vortex be of opposite sense to that of the aerofoil, then the lift on the system will be less than for the isolated aerofoil.

4. In illustration of the physical significance of formula (4) of the preceding section, let us consider the particular case where a translational flow is superimposed on a cylinder possessing a circulation and vortices are situated at great distances from the cylinder. In this case $\zeta=z$, $\chi'(z)=1$, and $a=1$. Then (4) assumes the form

$$Y+iX=-\rho V_\infty e^{-\theta i}\,[\Gamma-\Sigma\, I_K]-\rho i\Gamma\,\Sigma\,(I_K/2\pi b_K)+i\rho\sum_K\sum_E I_K I_E/[2\pi\,(b_K-a_E)].$$

The first term $-\rho V_\infty e^{-\theta i}\Gamma$ represents the force, produced in accordance with Joukovski's theorem, on the bound vortex of the cylinder by the translational flow, and the analogous one $\rho V_\infty e^{-\theta i} I_K$ gives the corresponding force on the image vortex I_K inside the cylinder.

The term $-\rho i\Gamma (I_K/2\pi b_K)$ denotes the force on Γ resulting from the velocity induced at the axis of the cylinder by the external vortex I_K.

Further, a term of the form $i\rho . I_E I_K / \{ 2\pi (b_K - a_E) \}$ gives the force on the image vortex I_E due to the induced velocity of the external vortex I_K.

Hence, for the case at hand, we obtain a theorem which may be regarded as a generalisation of that of Joukovski. " If a circular cylinder, possessing a circulation, lies in a fluid in which at infinity there is inserted a doublet and, at finite distances, a finite number of stationary vortices, then in the ensuing flow there arises a resultant to the forces, which are produced by the velocities due to the doublet and to each separate vortex, on the bound vortex of the cylinder and on the vortices that form the images within the cylinder of those outside."

" Each individual force is equal to the product of the density of the fluid, the intensity of the vortex, and the velocity of flow at the position of its axis due to the doublet or to a member of the external vortex system. Its direction is obtained from that of the velocity at the axis by rotating the velocity vector through a right angle in the opposite sense to the circulation of the vortex."

In other words, the resultant is composed of the forces produced in accordance with Joukovski's theorem on the bound vortex of the cylinder and on the images of the external vortices, by all the velocities due to the doublet and those vortices.

In the general case of a body of any form, it is apparently impossible to obtain such a simple formulation on account of the distortion of distances and directions in the flow through the conformal representation, which introduces into the formula terms dependent on $\chi'(z)$ and $\chi''(z)$.

5. The effect of a vortex belonging to the bound vortex system of an aerofoil briefly treated towards the end of §3, will be dealt with in greater detail in Part III. We shall pass on now to an account of the influence of vortices that are not bound to the aerofoil. This latter kind may be formed in those regions over its surface wherein conditions are created which cause the breakaway of the streamlines. It is a well-known fact that at the ridges of salient angles the velocity of flow is theoretically infinite in value and therefore in the vicinity of such ridges either there are formed vortex rollers, which have the effect of blunting them, or else there occurs a breakaway of the streamlines.

If an aerofoil possesses a sharp leading edge, then, as Joukovski has shown,[11] a vortex is created in front of it, giving rise to a firm resistance; and an analogous result is obtained with a rounded leading edge provided the angle of attack be sufficiently great. At the present day, however, this phenomenon may be said to have been adequately studied.[12]

One similar is to be observed at points where there are recesses in the aerofoil.

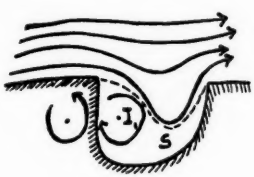

FIG. 3.

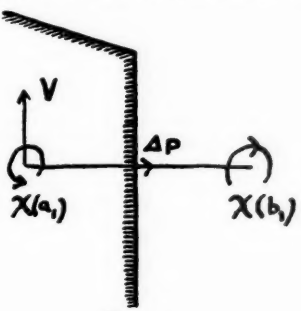

FIG. 4.

[11] " On Lifting Planes of the Antoinette Type." Trans. of the Physical Section of the Imperial Society of Friends of Natural Science, Vol. 15, No. 11, 1911.

[12] F. G. Schmidt. " The Theory of Drag in a Two-Dimensional Flow." Bulletin of the State Hydrological Institute, No. 18, 1917. S. N. Michurine. " The Vortex Theory of the Drag of an Aeroplane." Saratov, 1929.

Consider the case of a cavity in the surface of the aerofoil (Fig. 3). Here a breakaway of the streamlines can take place and in the hollow of the recess we shall have a layer of stationary fluid, separated by some surface S from that in motion. As a consequence of the existence of friction, a vortex I_1 will be formed with the sense of rotation shown in the figure. Such vortices which do not belong to the vortex system of the aerofoil are termed " parasite vortices," and their action we shall now study.

We saw in §3 (8) that the additional force obtained with a single vortex pair is given by

$$\Delta Y + \Delta \bar{X} = \{ \rho I_1 / \chi'(b_1) \} (dw_0/dz)_{z=b_1} + [i\rho I^2{}_1 \chi''(b_1)] / [4\pi \chi'^2(b_1)] + i\rho I^2{}_1 / \{ 2\pi (b_1 - a_1) \chi'(b_1) \}.$$

Since $[(dw_0/dz) \{ 1/\chi'(z) \}]_{z=b_1}$ is equal to the velocity V_{b_1} of the flow at the position of the vortex axis, then

$$\Delta Y + i\Delta X = \rho V_{b_1} I_1 + [i\rho I^2{}_1 \chi''(b_1)] / [4\pi \chi'^2(b_1)] + i\rho I^2{}_1 / [2\pi (b_1 - a_1) \chi'(b_1)].$$

Now such vortices can only be formed very close to the surface of the aerofoil, and therefore $(b_1 - a_1)$ is very small. Accordingly we need only retain the term $i\rho \cdot I^2{}_1 / \{ 2\pi (b_1 - a_1) \chi'(b_1) \}$ on the right hand side of this equation, for the others may be considered small in comparison with it.

Again, we have approximately :—

$$(b_1 - a_1) \chi'(b_1) = \chi(b_1) - \chi(a_1).$$

Consequently

$$\Delta Y + i\Delta X = \rho i \cdot I^2{}_1 / \{ 2\pi [\chi(b_1) - \chi(a_1)] \}.$$

The points $\chi(b_1)$ and $\chi(a_1)$ are respectively the axes of the parasite vortex and its image in the original ζ-plane (Fig. 4).

Let

$$\chi(b_1) - \chi(a_1) = re^{\alpha i}.$$

Then

$$\Delta Y + i\Delta X = \rho (|I|/2\pi r) e^{(\frac{1}{2}\pi - \alpha) i} \cdot |I|$$

where $|I|/2\pi r$ is equal to the velocity V, communicated to the image vortex at $\chi(a_1)$ by the vortex at $\chi(b_1)$.

Let

$$\Delta Y + i\Delta X = \Delta P \cdot (\sin\theta + i\cos\theta) = \Delta P \cdot e^{(\frac{1}{2}\pi - \theta) i}.$$

Then

$$\Delta P \cdot e^{(\frac{1}{2}\pi - \theta) i} = \rho \cdot V \cdot |I| \cdot e^{(\frac{1}{2}\pi - \alpha) i}.$$

Hence

$$\Delta P = \rho \cdot V \cdot |I|, \text{ and } \theta = \alpha.$$

These equations show that the parasite vortex induces a force which is directed along the straight line joining the axis of its image within the aerofoil to the axis of the vortex itself. In other words, the additional force created is equal in magnitude to $\rho |I| V$, and its direction is obtained from that of the velocity by turning through a right angle in the opposite sense to that of the circulation of the vortex, *i.e.*, we get Joukovski's theorem.

For the formation of parasite vortices, it is necessary that the stream should break away from the front wall of a recess; when this happens, the vortices are produced in such positions as that shown in Fig. 3, and the resulting force being directed backwards, augments the drag.

Let us apply this to the slotted wing. If the angle of attack be such that over the segments AB and $A'B'$ (Fig. 5) the velocities of the stream—and therefore the pressures on the air included within the slot—are equal, then there is no flow through the slot and the wing works as though continuous.

Consequently the preceding considerations are applicable here. At the extremities of the slot are formed vortices I_1 and I_2 (Fig. 6) which communicate velocities V_1 and V_2 to their respective images I'_1 and I'_2. Accordingly forces P_1 and P_2 are created, causing a head resistance. However, since the intensity

of these vortices is small, the corresponding increase in the drag will not be large.

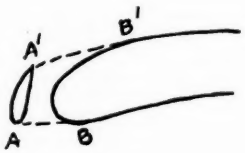

FIG. 5.

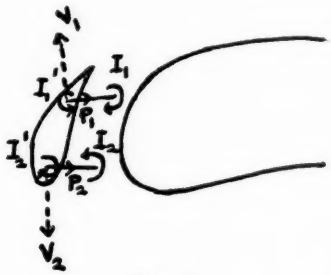

FIG. 6.

PART II.

DETERMINATION OF THE POINT OF BREAKAWAY OF THE STREAMLINES FROM THE SURFACE OF AN AEROFOIL.

1. In this section we shall introduce those initial considerations in the theory of the boundary layer which will be of service to us in the determination of the point of breakaway of the streamlines.

It is well-known that, within the limits of the thickness of the boundary layer, we have in lieu of the fundamental equations of hydrodynamics, the following (Prandtl's equations):—

$$u\,(\partial u/\partial x)+v\,(\partial u/\partial y)=-(1/\rho)\,(\partial p/\partial x)+\nu\,(\partial^2 u/\partial y^2)$$
$$\partial p/\partial y=0$$
$$\partial u/\partial x+\partial v/\partial y=0 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where the flow is assumed to be two-dimensional. The curvature of the wall we shall neglect; u and v are then the components of the velocity, parallel and perpendicular to the wall respectively.

The first of the equations (1) after integration and some transformation, gives the integral relation (von Kármán's equation):—

$$(d/dx)\int_0^h \rho u^2 dy - U\,(d/dx)\int_0^h \rho u dy = -h\,(dp/dx)-\mu\,(\partial u/\partial y)_{y=0} \quad . \quad (2)$$

where h is the thickness of the layer, and U the velocity on its outer surface. Kármán's integral equation possesses the following two advantages over Prandtl's system of equations:—

1. It contains but one unknown function u, and moreover, h depends only on the position of the point on the surface of the wall, *i.e.*, on x.
2. Its order has been reduced by integration as compared with that of the first equation in (1).

If $U\,(x)$, the distribution of the velocities on the outer surface of the layer, is known, then so is dp/dx, since from Bernoulli's equation we have:—

$$dp/dx=-\rho U U' \quad . \quad . \quad . \quad . \quad . \quad (3)$$

For the approximate solution of Kármán's equation a comparatively simple method has been given by Polhausen,[13] and is as follows:—

Let us represent the function sought in the form

$$u=ay+by^2+cy^3+dy^4$$

[13] K. Polhausen. "Zur näherungsweisen Integration der Differentialgleichung der laminaren Grenzschicht." Abh. aus dem Aerodyn. Inst. an der Technischen Hochschule zu Aachen. Heft 1, S.20.

and for the determination of a, b, c, d, which are unknown functions of x, apply the following boundary conditions:—

(1) On the inner boundary of the layer (where $y=0$) we have by a property of the boundary layer:—

$$u=0;\ v=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Hence from the first of the equations (1) we have

$$(\nu\partial^2 u/\partial y^2)_{y=0}=(1/\rho)\,(dp/dx)$$

and therefore by (3)

$$(\partial^2 u/\partial y^2)_{y=0}=-UU'/\nu \quad . \quad . \quad . \quad . \quad (5)$$

(2) At the outer boundary of the layer ($y=h$):—

$$u=U \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Further, since the force due to viscosity does not make its appearance there, then

$$(\partial u/\partial y)_{y=h}=0 \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Moreover, since the velocity u asymptotically approaches the value U, Polhausen increased the order of contact, putting:—

$$(\partial^2 u/\partial y^2)_{y=h}=0 \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Equations (5), (6), (7) and (8) enable the coefficients a, b and d to be found, and their values are as follows:—

$$a=(U/6h)\,(12+\lambda);\ b=-U\lambda/2h^2;$$
$$c=-(U/2h^3)\,(4-\lambda);\ d=(U/6h^4)\,(6-\lambda);$$

where $\lambda=U'h^2/\nu$.

Substituting these in (2), we obtain after some reduction the equation (Polhausen's):—

$$(d\lambda/dx)\,(U/U')-\lambda UU''/U'^2=0.8\,[-907.2+1670.4\,\lambda-(47.4+4.8\,UU''/U'^2)\,\lambda^2$$
$$-(1+UU''/U'^2)\,\lambda^3]/[-213.12+5.76\,\lambda+\lambda^2] \quad . \quad . \quad (9)$$

This is the equation which we shall apply to the determination of the point of breakaway of the streamlines.

To obtain that point it is necessary to find a value of x such that $(\partial u/\partial y)_{y=0}=0$, *i.e.*, a must be zero, whence $\lambda=-12$.

Again, since $\lambda=U'h^2/\nu$ then $\lambda=0$ at the point where U reaches a maximum. Taking the origin of co-ordinates there, we thus have $u'=0$ for $x=0$, $y=0$.

Hence if $\lambda=F(x)$ be the integral of (9) which vanishes for $x=0$, then the point of breakaway x_0 will be found on solving the equation

$$F(x)=-12.$$

From the preceding it is evident that for the determination of the point of breakaway it is necessary to know the function $U(x)$, *i.e.*, the velocity on the outer surface of the layer when the breakaway occurs, and this in turn requires the knowledge of the position of that point. Consequently Prandtl's theory, as it stands at present, does not admit of the possibility of determining the point of breakaway without some supplementary data, such as, for example, the distribution of the velocities or pressures on the surface of the aerofoil.

In the sequel we shall examine two cases of the distribution of velocity and pressure on the upper surface of an aerofoil according respectively as the position of the point of breakaway is or is not known.

2. When an aerofoil works under conditions of an entirely streamline flow, the point of breakaway of the streamlines is situated at the trailing edge. In what follows we shall assume that the aerofoil has the profile of the inverse of a parabola; consequently, the trailing edge will be sharp, and this completely defines the position of the point of breakaway.

The substitution

$$\zeta=z_1+\{(1-\epsilon)^2\cos^2\tfrac{1}{2}\alpha\}/z_1 \quad . \quad . \quad . \quad . \quad (1)$$

will transform the unit circle C_1 on the z_1-plane into the perimeter C'_1 of the inverse of a parabola on the ζ plane, the skeleton C' of which corresponds to

the circle C of radius $(1-\epsilon)$, ϵ[14] being the parameter characterising the thickness of the aerofoil (Figs. 7*a* and 7*b*).

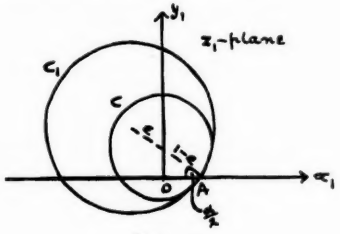

FIG. 7*a*.

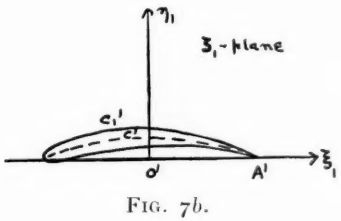

FIG. 7*b*.

Transferring the origin on the z_1-plane to the point $z_1=(1-\epsilon)\cos\frac{1}{2}\alpha$ (Fig. 8), we have the formula:—

$$z_1=z_2+(1-\epsilon)\cos\tfrac{1}{2}\alpha.$$

Whence, substituting this expression in (1) we shall have

$$\zeta=z_2+(1-\epsilon)\cos\tfrac{1}{2}\alpha+\{(1-\epsilon)^2\cos^2\tfrac{1}{2}\alpha\}/\{z_2+(1-\epsilon)\cos\tfrac{1}{2}\alpha\} \quad . \quad (2)$$

Rotate the co-ordinate axes on the z_2-plane through an angle $-\frac{1}{2}\alpha$ (Fig. 8), then $z_2=z_3\,.\,e^{-\frac{1}{2}\alpha i}$. From (2) we get:—

$$\zeta=z_3e^{-\frac{1}{2}\alpha i}+(1-\epsilon)\cos\tfrac{1}{2}\alpha+\{(1-\epsilon)^2\cos^2\tfrac{1}{2}\alpha\}/\{(z_3e^{-\frac{1}{2}\alpha i}+(1-\epsilon)\cos\tfrac{1}{2}\alpha\} \quad (3)$$

Finally, transfer the origin on the z_3-plane to the centre of the circle C_1 (Fig. 8), then $z_3=z_2-1$, and from (3) we get, dropping the suffixes,

$$\zeta=e^{-\frac{1}{2}\alpha i}(z-1)+(1-\epsilon)\cos\tfrac{1}{2}\alpha+\{(1-\epsilon)^2\cos^2\tfrac{1}{2}\alpha\}/\{(z-1)e^{-\frac{1}{2}\alpha i}+(1-\epsilon)\cos\tfrac{1}{2}\alpha\} \quad (4)$$

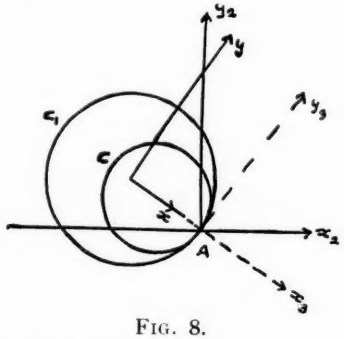

FIG. 8.

This is the final form of the transformation sought, giving the correspondence between the exterior part of the circle C_1 and the exterior part of the inverse of a parabola constructed on an arc of radius $(1-\epsilon)/\sin\frac{1}{2}\alpha$.

From (4) we have

$$d\zeta/dz=e^{-\frac{1}{2}\alpha i}\left[1-\{(1-\epsilon)^2\cos^2\tfrac{1}{2}\alpha\}/\{(z-1)e^{-\frac{1}{2}\alpha i}+(1-\epsilon)\cos\tfrac{1}{2}\alpha\}^2\right]$$
$$=e^{-\frac{1}{2}\alpha i}(z-1)\left[(z-1)e^{-\frac{1}{2}\alpha i}+2(1-\epsilon)\cos\tfrac{1}{2}\alpha\right]/\left[(z-1)e^{-\frac{1}{2}\alpha i}+(1-\epsilon)\cos\tfrac{1}{2}\alpha\right]^2 \quad (5)$$

The potential function of the flow against a cylinder possessing a circulation Γ is of the form:—

$$w=V_\infty e^{-\theta i}(z+e^{2\theta i}/z)+(\Gamma/2\pi i)\log z$$

whence

$$dw/dz=V_\infty e^{-\theta i}(1-e^{2\theta i}/z^2)+(\Gamma/2\pi i)(1/z) \quad . \quad . \quad . \quad (6)$$

[14] Frequently in aerodynamic literature, the ratio of the radius of the larger circle C_1 to that of the smaller C is expressed as $1+\epsilon_1$. The relationship between the thickness parameters ϵ and ϵ_1 is obviously: $1+\epsilon_1=1/(1-\epsilon)$.

If the axes be so disposed that the point of breakaway corresponds to the point $z=1$, then at the latter, in accordance with Joukovski's fundamental postulate, $(dw/dz)=0$. Thus :—

$$V_\infty e^{-\theta i}(1-e^{2\theta i})+\Gamma/2\pi i=0 \quad . \quad . \quad . \quad . \quad (7)$$

On eliminating Γ between (6) and (7), we obtain the equation

$$dw/dz=V_\infty e^{-\theta i}([z-1]/z)(1+e^{2\theta i}/z) \quad . \quad . \quad . \quad (8)$$

From (5) and (8) we have :—

$$dw/d\zeta=(dw/dz)(dz/d\zeta)$$

$$=V_\infty e^{-\theta i}(1/z)(1+e^{2\theta i}/z)\,e^{\alpha i}\,[(z-1)e^{-\frac{1}{2}\alpha i}+(1-\epsilon)\cos\tfrac{1}{2}\alpha]^2/[(z-1)e^{-\frac{1}{2}\alpha i}+2(1-\epsilon)\cos\tfrac{1}{2}\alpha] \quad . \quad . \quad (9)$$

Since V_ζ the magnitude of the velocity at any point is equal to $|dw/d\zeta|$ then :—

$$V_\zeta=(V_\infty/|z|)\,|e^{-\theta i}+e^{\theta i}/z|\,.\,|(z-1)e^{-\frac{1}{2}\alpha i}+(1-\epsilon)\cos\tfrac{1}{2}\alpha|^2/|(z-1)e^{-\frac{1}{2}\alpha i}+2(1-\epsilon)\cos\tfrac{1}{2}\alpha| \quad . \quad . \quad (10)$$

To obtain the velocity at a point situated on the surface of the aerofoil, put $z=e^{\lambda i}$. Then

$$V_\zeta=V_\infty|e^{-\theta i}+e^{(\theta-\lambda)i}|\,.\,|(e^{\lambda i}-1)\,e^{-\frac{1}{2}\alpha i}+(1-\epsilon)\cos\tfrac{1}{2}\alpha|^2/|(e^{\lambda i}-1)\,e^{-\frac{1}{2}\alpha i}+2(1-\epsilon)\cos\tfrac{1}{2}\alpha| \quad . \quad . \quad (11)$$

Now

$$|e^{-\theta i}+e^{(\theta-\lambda)i}|=2\cos(\theta-\tfrac{1}{2}\lambda) \quad . \quad . \quad . \quad . \quad (12)$$

$$|(e^{\lambda i}-1)\,e^{-\frac{1}{2}\alpha i}+(1-\epsilon)\cos\tfrac{1}{2}\alpha|^2$$

$$=[(1-\epsilon)^2\cos^2\tfrac{1}{2}\alpha-4(1-\epsilon)\cos\tfrac{1}{2}\alpha\sin\tfrac{1}{2}\alpha\sin(\tfrac{1}{2}\lambda-\tfrac{1}{2}\alpha)+4\sin^2\tfrac{1}{2}\lambda] \quad (13)$$

$$|(e^{\lambda i}-1)\,e^{-\frac{1}{2}\alpha i}+2(1-\epsilon)\cos\tfrac{1}{2}\alpha|$$

$$=2\{(1-\epsilon)^2\cos^2\tfrac{1}{2}\alpha-2(1-\epsilon)\cos\tfrac{1}{2}\alpha\sin\tfrac{1}{2}\alpha\sin(\tfrac{1}{2}\lambda-\tfrac{1}{2}\alpha)+\sin^2\tfrac{1}{2}\lambda\}^{\frac{1}{2}} \quad (14)$$

Substituting in (11) the values of the moduli from (12), (13) and (14), we have :—

$$V_\zeta=V_\infty\cos(\theta-\tfrac{1}{2}\lambda)\{(1-\epsilon)^2\cos^2\tfrac{1}{2}\alpha-4(1-\epsilon)\cos\tfrac{1}{2}\alpha\sin\tfrac{1}{2}\alpha\sin(\tfrac{1}{2}\lambda-\tfrac{1}{2}\alpha)$$
$$+4\sin^2\tfrac{1}{2}\lambda\}/\{(1-\epsilon)^2\cos^2\tfrac{1}{2}\alpha-2(1-\epsilon)\cos\tfrac{1}{2}\alpha\sin\tfrac{1}{2}\alpha\sin(\tfrac{1}{2}\lambda-\tfrac{1}{2}\alpha)$$
$$+\sin^2\tfrac{1}{2}\lambda\}^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad (15)$$

This formula thus enables the magnitude of the velocity to be calculated at any point on the surface of an aerofoil of the inverse of a parabola type provided that the flow over the aerofoil is entirely streamline, *i.e.*, when the trailing edge is the point of breakaway.

3. The theoretical deduction concerning the law of pressure variation[15] is in sufficient measure confirmed by experiment which, in addition, reveals the interesting fact that even when the point of breakaway is displaced from the trailing edge an approximately linear distribution is obtained throughout the interval between the point of minimum pressure and the point of breakaway.

Employing this result, it is a simple matter to solve the problem, proposed in §1 of the present part, of determining the point of breakaway from the upper surface of an aerofoil. With this object we shall take as our fundamental equation §1 (9), viz. :—

$$(d\lambda/dx)(U/U')-\lambda UU''/U'^2=0.8\,[-9072+1670.4\,\lambda-(47.4+4.8\,UU''/U'^2)\,\lambda^2$$
$$-(1+UU''/U'^2)\,\lambda^3]/[-213.12+5.76\,\lambda+\lambda^2] \quad . \quad . \quad (1)$$

Since by a property of the boundary layer the pressure on the surface of an aerofoil is equal to that on the outer surface of the layer, then over the latter the pressure will vary in accordance with a linear law, *i.e.*, $dp/dx=\text{const.}$ From §1 (3), we have :—

$$dp/dx=-\rho UU' \quad . \quad . \quad . \quad . \quad . \quad (2)$$

[15] In the case where the point of breakaway is situated at the trailing edge, the author (pages 31-32 of the Russian Text), on substituting in Bernouilli's equation the expression §2(15) for the velocity, shows—under the assumption that $\epsilon \leq .3$, $\alpha \leq 20°$, and $\theta \leq 15°$—that the pressure varies linearly over the upper surface of the aerofoil throughout the interval between the point of minimum pressure and the point of breakaway.

On differentiating (2) with respect to x, we get, since dp/dx is a constant:—

$$U d^2U/dx^2 + (dU/dx)^2 = 0$$

or

$$UU''/U'^2 = -1 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Substituting this expression in (1), the latter becomes:—

$$(U/U')\,(d\lambda/dx) = 0.8\,[-9072 + 1670.4\,\lambda - 42.6\,\lambda^2]/[-213.12 + 5.76\,\lambda + \lambda^2] - \lambda$$

or

$$(U'/U)\,dx = \{\,[-213.12 + 5.76\,\lambda + \lambda^2]/[-7257.6 + 1549.4\,\lambda - 39.8\,\lambda^2 - \lambda^3]\,\}\,d\lambda$$
$$= R\,(\lambda)\,d\lambda \text{ (say)} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

From §1, the limits of integration will be 0 and x_0 for x, and 0 and -12 for λ. Hence

$$\int_0^{x_0} (U'/U)\,dx = \int_0^{-12} R\,(\lambda)\,.\,d\lambda$$

i.e.,

$$\log\,(U_{max}/U_0) = \int_{-12}^{0} R\,(\lambda)\,.\,d\lambda \quad . \quad . \quad . \quad . \quad (5)$$

where U_0 = the velocity at the point of breakaway.

The definite integral on the right hand side will be found to have the value 0.160 (see §9). Therefore

$$U_{max}/U_0 = e^{0.160} = 1.2 \text{ approx.}$$

Hence we obtain the following fundamental result:—"If in the interval between the point of minimum pressure and the point of breakaway of the streamlines the pressure varies according to a linear law, then the ratio of the velocity at the former to that at the latter is equal to 1.2."

It should be noted that the linearity of the pressure distribution forms a basic condition for the obtaining of this result. In cases of flow around bodies whose form differs greatly from that of an aerofoil a linear variation of pressure is entirely uncomplied with, and so the above would be quite inapplicable, for instance, to the flow against a cylinder.

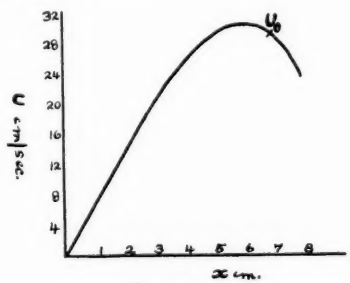

FIG. 9.

Fig. 9 gives the velocity distribution over the surface of a cylinder as determined by Hiemenz and Polhausen.[16] Since $U_{max} = 30.6$ cm./sec. and the point of breakaway found for x (measured from the stagnation point) = 6.98 cm. where $U_0 = 29.5$ cm./sec., then

$$U_{max}/U_0 = 1.047,$$

which disagrees entirely with the result obtained above. In the present case it appears that the curvature of the cylinder is an important factor whilst that of

[16] See §1. Reference (13).

an aerofoil within the limits of the portion of the upper surface considered, is negligible.

This example shows that for aerofoils of very thick section (ϵ large) or of marked curvature (a large), the result obtained is not valid.

4. The result deduced in the preceding section permits of the immediate solution of the question of determining the greatest angle of attack for which a given aerofoil will work in an entirely streamline flow. Such an angle we shall term a "limiting angle of attack."

We shall confine ourselves, as before, to a profile of the form of the inverse of a parabola.

Under the condition of complete continuity of flow at the limiting angle of attack, the trailing edge—to which corresponds the value $\lambda=0$—will be the point of breakaway. In which case from the formula :—

$$U = V_\infty \cos(\theta-\tfrac{1}{2}\lambda)\,[(1-\epsilon)^2\cos^2\tfrac{1}{2}a-4(1-\epsilon)\cos\tfrac{1}{2}a\sin\tfrac{1}{2}\lambda\sin(\tfrac{1}{2}\lambda-\tfrac{1}{2}a) + 4\sin^2\tfrac{1}{2}\lambda]/[(1-\epsilon)^2\cos^2\tfrac{1}{2}a-2(1-\epsilon)\cos\tfrac{1}{2}a\sin\tfrac{1}{2}\lambda\sin(\tfrac{1}{2}\lambda-\tfrac{1}{2}a)+\sin^2\tfrac{1}{2}\lambda]^{\frac{1}{2}} \quad (1)$$

the velocity U_0 will be

$$U_0 = V_\infty(1-\epsilon)\cos\tfrac{1}{2}a\cos\theta \quad . \quad . \quad . \quad . \quad (2)$$

Again, since the maximum velocity occurs near the leading edge, which for small values of a is given approximately by $\lambda=\pi$, then by (1) we have :—

$$U_{max} = V_\infty \sin\theta\,[(1+\epsilon)^2\cos^2\tfrac{1}{2}a+4\sin^2\tfrac{1}{2}a]/[\epsilon^2\cos^2\tfrac{1}{2}a+\sin^2\tfrac{1}{2}a]^{\frac{1}{2}} \quad (3)$$

When a is small, $\cos\frac{1}{2}a\approx 1$ and $\sin\frac{1}{2}a\approx 0$. Then

$$U_{max} = V_\infty\{(1+\epsilon)^2/\epsilon\}\sin\theta \quad . \quad . \quad . \quad . \quad (3')$$

From (2) and (3′), we have :—

$$U_{max}/U_0 = \{(1+\epsilon)^2/\epsilon(1-\epsilon)\}\tan\theta \quad . \quad . \quad . \quad (4)$$

It was shown that when the point of breakaway is situated at the trailing edge the pressure variation is linear and therefore $U_{max}/U_0=1.2$.

Substituting this value in (4), we obtain the following formula for the limiting angle of attack θ_0 :—

$$\tan\theta_0 = 1.2\,\epsilon(1-\epsilon)/(1+\epsilon)^2 \quad . \quad . \quad . \quad . \quad (5)$$

The following table gives the values of θ_0 corresponding to certain values of ϵ :—

ϵ	$\tan\theta_0$	θ_0
0.05	0.0516	3°
0.10	0.0892	5°
0.20	0.1333	7·5°
0.30	0.1490	8.5°

If we were dealing with aerofoils of finite span, then since the correction for downwash amounts to about 3° for the cases at hand, the corresponding limiting angles would be 6°, 8°, 10.5°, and 11.5° respectively.

It should be noted that (5) is strictly true only for a symmetrical aerofoil ($a=0$), but may be considered approximately so for any small value of a; moreover, this formula gives very inaccurate approximations with large values of ϵ, since in such cases U_{max} occurs at an appreciable distance from the leading edge.

The determination of the parameters (a, ϵ) of the aerofoil possessing the maximum limiting angle of attack affords no difficulty if we assume a to be small. From (2) and (3) we have :—

$$\tan\theta_0 = 1.2\,(1-\epsilon)\,(\epsilon^2+\tan^2\tfrac{1}{2}a)^{\frac{1}{2}}/\{(1+\epsilon)^2+4\tan^2\tfrac{1}{2}a\} \quad . \quad (6)$$

It is required to find the maximum value of (6) when both ϵ and $\tan\frac{1}{2}a$ vary. Denoting $\tan\frac{1}{2}a$ by t and differentiating with respect to ϵ and t in turn, we get for their determination the equations :—

$$\{\epsilon-2\epsilon^2-t^2\}\{(1+\epsilon)^2+4t^2\}-2(\epsilon^2+t^2)(1-\epsilon^2)=0$$
$$t(1+2\epsilon-7\epsilon^2-4t^2)=0 \quad . \quad . \quad . \quad . \quad (7)$$

The pair of values $t=0$, $\epsilon=\frac{1}{3}$, yields a maximum.

Again, substituting $t^2=(1+2\epsilon-7\epsilon^2)/4$ in the first equation of (7) we have:—

$$(1-\epsilon)^2 \,.\, (1+3\epsilon)=0, \textit{ i.e.}, \epsilon=1 \text{ or } -\tfrac{1}{3}$$

The second of these is inapplicable, whilst the first makes t imaginary. Thus the single relevant solution is:—

$$\epsilon=\tfrac{1}{3}, \tan \tfrac{1}{2}\alpha=0, \textit{ i.e.}, \alpha=0.$$

Hence the aerofoil sought is the symmetrical inverse of a parabola for which $\epsilon=\frac{1}{3}$. The corresponding limiting angle of attack (after correction for downwash, 3°) is 11.5°.

The circumstance that an increase in ϵ beyond a certain value involves a deterioration in the qualities of an aerofoil in view of the decrease in the limiting angle of attack is evident *a priori* if only from the fact that by increasing ϵ indefinitely we obtain in the limit a circular cylinder.

5. Limiting angles obtained from formula (5) or (6) of the preceding section prove too small, for the study of experimental data shows that in reality aerofoils work in a streamline flow at angles of attack considerably in excess of the limit imposed by these formulæ.

As a preliminary to the solution of this question, let us find the angle of attack at which the point of breakaway of the streamlines moves over to a given point on the upper surface of the aerofoil.

Let the point in question correspond to $z=e^{\lambda_0 i}$. By formulæ already deduced we have:—

$$U_0=V_\infty \cos(\theta-\tfrac{1}{2}\lambda_0)\,[(1-\epsilon)^2\cos^2\tfrac{1}{2}\alpha-4(1-\epsilon)\cos\tfrac{1}{2}\alpha\sin\tfrac{1}{2}\lambda_0\sin(\tfrac{1}{2}\lambda_0-\tfrac{1}{2}\alpha)$$
$$+4\sin^2\tfrac{1}{2}\lambda_0]/[(1-\epsilon)^2\cos^2\tfrac{1}{2}\alpha-2(1-\epsilon)\cos\tfrac{1}{2}\alpha\sin\tfrac{1}{2}\lambda_0\sin(\tfrac{1}{2}\lambda_0-\tfrac{1}{2}\alpha)+\sin^2\tfrac{1}{2}\lambda_0]^{\frac{1}{2}} \quad (1)$$

$$U_{\max}=V_\infty \sin\theta\,[(1+\epsilon)^2\cos^2\tfrac{1}{2}\alpha+4\sin^2\tfrac{1}{2}\alpha]/[\epsilon^2\cos^2\tfrac{1}{2}\alpha+\sin^2\tfrac{1}{2}\alpha]^{\frac{1}{2}} \quad (2)$$

Since at the point of breakaway $U_{\max}/U_0=1.2$, then dividing (1) by (2) and assuming $\alpha\approx 0$, we get:—

$$[\{\cos(\theta-\tfrac{1}{2}\lambda_0)\}/\sin\theta]$$
$$[\{(1-\epsilon)^2+4\epsilon\sin^2\tfrac{1}{2}\lambda_0\}/\{(1-\epsilon)^2+2\epsilon\sin^2\tfrac{1}{2}\lambda_0-\sin^2\tfrac{1}{2}\lambda_0\}]\,[\epsilon/(1+\epsilon)^2]$$
$$=1/1.2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

This equation yields the required angle of attack θ. Let us calculate, for various values of ϵ, the corresponding θ at which the point of breakaway reaches the middle of the upper surface.

Here $z=e^{\frac{1}{2}\pi i}$, and (3) becomes:—

$$\cot\theta=\{(1+\epsilon)^2/1.2\,\epsilon\,(1+\epsilon^2)\}\,(1-2\epsilon+2\epsilon^2)^{\frac{1}{2}}-1 \quad . \quad . \quad (4)$$

ϵ	$\cot\theta$	θ	θ_0*	$\Delta\theta$
0.05	16.44	3.5°	3°	0.5°
0.10	8.040	7°	5°	2°
0.20	3.758	15°	7.5°	7.5°
0.30	2.280	24°	8.5°	15.5°

Hence the following practically important result is obtained:—In the case of aerofoils of thin section ($\epsilon=0.05$) the point of breakaway of the streamlines upon leaving the trailing edge is displaced very rapidly along the upper surface, so that, with a very small increment in the angle of attack beyond the limiting angle, the aerofoil commences to work wholly in a discontinuous flow, a marked diminution in lift and increase in drag being necessarily concomitant to this. By increasing the thickness of the section, the rate of displacement of the point of breakaway with respect to an increment in the angle of attack beyond the limiting angle is slowed down, and therefore the deterioration in the efficiency of the aerofoil as dependent upon such increments, takes place comparatively slowly.

* The angle at which the point of breakaway commences to depart from the trailing edge (*i.e.*, limiting angle of attack) reproduced from the Table in §4.

If this result be portrayed on the polar diagram, we shall obtain the following theoretical schemes for the polars of thin and thick sections (Figs. 10 and 11).

FIG. 10.

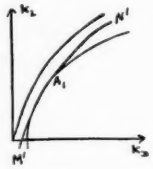

FIG. 11.

The polar of a thin aerofoil, for small angles of attack, runs parallel to the parabola of induced drag, the increased resistance for the actual aerofoil being due to profile drag; however, at a certain point A, corresponding to the limiting angle of attack, it deviates from the parallel curve MN, and very near to A reaches a point which corresponds to the angle of attack for which the aerofoil begins to work wholly in a discontinuous flow.

With aerofoils of thick section beyond the point A' (limiting angle of attack) the polar deviates but slowly from the parallel curve $M'N'$ and the régime of complete breakaway of streamlines is entered upon at angles considerably larger than the limiting angle of attack.

The above-mentioned discrepancy in the limiting angles of attack, as given respectively by theory and experiment, is particularly marked with thin aerofoils. In the case of such an aerofoil, as the researches of N. E. Joukovski, F. V. Schmidt, and S. N. Michurine have shown, there is formed a vorticular roller of air and this produces the effect of virtually thickening the aerofoil. Consequently the limiting angle of attack is increased. This possibly explains, in principal measure, the discrepancy between the theoretical and experimental values of such angles in the case of aerofoils of thin section.

Again, it is extremely probable that a slight displacement of the point of breakaway from the trailing edge has scarcely any repercussion on the flight qualities of an aerofoil and therefore on its polar. Accordingly a point such as A (or A') on the polar which nominally corresponds to the commencement of the departure from the trailing edge of the point of breakaway, in reality denotes a state for which that point is already appreciably displaced in view of the considerable decrease in lift and increase in drag that ensues. This possibly accounts for the discrepancy in the case of aerofoils of thick section[17] and, also to some extent, that in the case of those of thin section. (See also §6, Part III.)

6. All the preceding deductions were obtained under the assumption of a linear variation of pressure over the upper surface of the aerofoil in the interval between the point of minimum pressure and the point of breakaway of the streamlines. The question naturally arises as to whether it be possible to retain them all for wider assumptions concerning the law of pressure variation. Such is easily seen to be the case.

Taking Polhausen's equation, §1 (9), it is obvious that the variables can be separated if

$$UU''/U'^2 = C, \text{ a constant} \quad . \quad . \quad . \quad . \quad (1)$$

The whole of the preceding theory was obtained under the supposition that $C = -1$.

We shall now determine the nature of the results got for any value of C.

[17] After correction for downwash, the mean value of the discrepancy amounts to about 5° on comparison with Göttingen experimental data.

Substituting for (1) in Polhausen's equation, the latter is reduced to the form :—

$$dU/U = \{ f(\lambda) \cdot d\lambda \} / \{ \phi(\lambda) + C \cdot \psi(\lambda) \} = R(\lambda) \cdot d\lambda \quad . \quad (2)$$

where

$$f(\lambda) = \lambda^2 + 5.76\,\lambda - 213.12$$
$$\phi(\lambda) = -0.8\,\lambda^3 - 37.92\,\lambda^2 + 1336.32\,\lambda - 7257.6$$
$$\psi(\lambda) = 0.2\,\lambda^3 + 1.92\,\lambda^2 - 213.12\,\lambda.$$

From (2) :—

$$\log (U_{max}/U_o) = \int_{-12}^{0} R(\lambda) \cdot d\lambda$$

$$i.e.,\ U_{max}/U_o = e^S \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\text{where } S = \int_{-12}^{0} R(\lambda) \cdot d\lambda$$

For the evaluation of the integral, tables of values of the functions $f(\lambda)$, $\phi(\lambda)$, and $\psi(\lambda)$ for integral values of λ from 0 to -12 were constructed as follows :—

$f(\lambda) = \lambda^2 + 5.76\,\lambda - 213.12.$

λ	0	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10	−11	−12
$f(\lambda)$	−213.12	−217.88	−220.40	−221.40	−220.16	−216.92	−211.68	−204.44	−195.20	−183.96	−170.72	−155.48	−138.24

$\phi(\lambda) = -0.8\,\lambda^3 - 37.92\,\lambda^2 + 1336.32\,\lambda - 7257.6.$

λ	0	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10	−11	−12
$\phi(\lambda)$	−7257.60	−8031.04	−10075.52	−11586.24	−13158.40	−14787.20	−16467.84	−18195.52	−19965.44	−21772.80	−23612.80	−25479.64	−27371.52

$\psi(\lambda) = 0.2\,\lambda^3 + 1.92\,\lambda^2 - 213.12\,\lambda.$

λ	0	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10	−11	−12
$\psi(\lambda)$	0	214.84	432.32	651.24	870.40	1088.60	1304.64	1517.32	1725.44	1927.80	2123.20	2310.44	2488.32

With these data the integral may be evaluated approximately by application of the trapezoidal rule, viz. :—

$$S = \int_{-12}^{0} R(\lambda) \cdot d\lambda = \{ R(0) + R(-12) \}/2 + R(-1) + R(-2) + \ldots + R(-11)$$

The following table gives the values of S for various values of C :—

C	S	C	S	C	S
−60	0.046	−6	0.127	3	0.204
−50	0.050	−5	0.132	4	0.224
−40	0.060	−4	0.137	5	0.242
−30	0.070	−3	0.144	6	0.271
−20	0.086	−2	0.152	7	0.306
−10	0.109	−1	0.160	8	0.366
−9	0.115	0	0.170	9	0.458
−8	0.118	1	0.179	10	0.662
−7	0.123	2	0.191	—	—

Now from (1) we have :—

$$U' = AU^C \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Since it is a condition of the problem that, in the interval considered, $U' < 0$, then A must be taken as negative and therefore we shall write (4) as :—

$$U' = -AU^C \quad . \quad . \quad . \quad . \quad . \quad (5)$$

So that finally :—

$$U = [B - A(1-C)x]^{1/(1-C)} \quad . \quad . \quad . \quad . \quad (6)$$

Equation (1) does not contain x, which may therefore be measured from an arbitrary point on the surface of the wing and we shall reckon it from that point where the velocity is a maximum. Then for $x = 0$, $U = U_{max}$, and (6) becomes :—

$$U = [U_{max}^{(1-C)} - A(1-C)x]^{1/(1-C)} \quad . \quad . \quad . \quad (7)$$

It is readily verified that the curve of pressure distribution obtained from this equation will be convex or concave with respect to the directions of the axes in Fig. 12 according as C is $<$ or >-1 ; for $C = -1$ we have the linear variation.

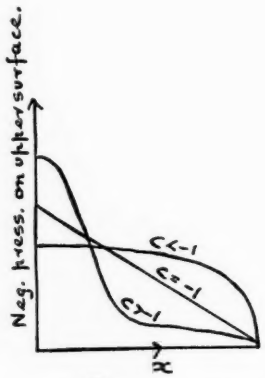

FIG. 12.

Hence we obtain the following approximate method for the determination of the point of breakaway.

Given the distribution of velocity (or pressure) as determined from experiment, adjust the constants A and C so that the distribution given by (7) agrees with it as closely as possible. Knowing C we at once obtain S from the table. The location of the point of breakaway, x_0 is then given by :—

$$U_{max}/e^S = [U_{max}^{(1-C)} - A(1-C)x_0]^{1/(1-C)}$$

In the case of a circular cylinder under this scheme it would be necessary to take C equal to about -60.

In illustration[18] of the method let us consider the cylinder (diameter 9.75 cm.) mentioned in § 3. The velocity distribution over the upper surface was found by Hiemenz to be given by the empirical formula :—

$$U = 7.151\,x - 0.04497\,x^3 - 0.00033\,x^5$$

x here being measured along the circumference from the stagnation point. This formula yields :—

$$U_{max} = 30.6 \text{ cm./sec. at } x = 6.05 \text{ cm.}$$

and at $x =$ (say) 6.50 cm., $U = 30.3$ cm./sec.

Taking, as suggested above, $C = -60$ the constant A in (7) will thus be determined by the condition :—

$$x = 0.45 \text{ cm.}, \quad U = 30.3 \text{ cm./sec.}$$

[18] This numerical example does not appear in the original Russian text.

Formula (7) will then assume the form :—

$$U = [10^{87}\ (4{,}240 - 4{,}270\ x)]^{1/61}$$

and will be found—over the range of its applicability here (about 1 cm.)—to represent the empirical velocity distribution quite accurately. Thus when $x = 0.95$ cm., U is got equal to 29.1 cm./sec. ; Hiemenz's formula on putting $x = 7.00$ cm., likewise gives $U = 29.1$ cm./sec.

Now from the table we have when $C = -60$, $S = 0.046$ and therefore $e^S = 1.047$. Hence at the point of breakaway :—

$$30.6/1.047 = [10^{87}\ (4{,}240 - 4{,}270\ x_0)]^{1/61}$$

or

$$x_0 = 0.93 \text{ cm.}$$

The value as determined experimentally by Hiemenz was, on taking the point of maximum velocity as origin :—

$$(6.98 - 6.05) \text{ cm.} = 0.93 \text{ cm.}$$

In conclusion we would remark that the theory of the breakaway of the streamlines from the surface of a wing appears to be—in the present development of aerodynamic theory—a fundamental problem, the full solution of which is extremely important for the resolution of technical questions connected with improvement in the construction of the wing. The approximate solution discussed here forms only the first step to the complete solution of the problem under review.

The question now arises as to whether it be possible to dispense altogether with any empirical data on the distribution of velocity or pressure and to determine the point of breakaway merely from the knowledge of the geometrical properties of the body and its disposition relative to the flow.

The following process naturally suggests itself. Suppose, to begin with, that at a given angle of attack the breakaway commences at the trailing edge of the aerofoil ; then, by the application of general theorems, obtain the velocity distribution, $U_1(x)$, on the outer surface of the boundary layer and, from Polhausen's equation, the corresponding position of the point of breakaway x_1. This gives a first approximation to its true position. With this knowledge construct the corresponding flow and a new velocity distribution $U_2(x)$ from which, on applying the aforesaid equation, a more accurate value x_2 is found. Repeating this process a number of times, we obtain in succession x_1, $x_2 \ldots x_n$, and assuming the existence of a limit (which is very probable), we shall get the true position of the point of breakaway as the limit x_n $(n \to \infty)$. But such a method of procedure—a method of successive approximations—is, however, unfeasible, in the present state of the theory for the following reasons :—

1. Given the position of the point of breakaway from the surface of an aerofoil, it is very difficult to determine the potential function of the corresponding flow and the velocity distribution in view of the extraordinary complexity of the theory of discontinuous flow in the case of curved surfaces.
2. The determination of the point of breakaway for a given velocity distribution over the outer surface of the boundary layer calls for the integration of Polhausen's equation and this in general presents great analytical difficulties.

From the point of view of the considerations expressed above the investigation of these two particular problems also forms an immediate objective on the theory of an aerofoil.

NOTE.—An interesting contribution to the subject was made subsequently in 1934 by A. A. Kosmodemyanski, a pupil of Prof. Golubev, who, rejecting the Polhausen boundary condition $(\partial^2 u / \partial y^2)_{y=h} = 0$, proposed a modification of the Polhausen method. For an account, with examples of its application to circular and elliptical cylinders and also to the symmetrical Joukovski aerofoil, see Trans. of C.A.H.I., No. 215 (April, 1935).

Part III.

Theory of the Action of a Slat.

1. The results of Part II show that a breakaway of the streamlines takes place if the fall in the velocity attains a certain magnitude. Hence it follows that any method that permits of the equalisation of the velocities over the upper surface, increases the limiting angle of attack for continuity of flow and therefore improves the action of the aerofoil. Several such methods could be mentioned, but the simplest and most readily applied in practice consists in adding, close to the surface of the aerofoil, a vortex to render the velocity distribution uniform. This vortex is realised constructionally in the form of a small auxiliary aerofoil which works in a smooth flow and consequently produces in the stream around the main aerofoil an effect equivalent to that of a vortex fixed near the latter's surface. Hence the following fundamental problem is indicated: To determine the influence of a vortex, situated in the vicinity of an aerofoil, on the distribution of the velocity over the upper surface. We shall proceed directly to the solution of this question.

The potential function of the flow against a cylinder, with a fundamental circulation Γ, in the presence of a vortex of strength K at the point $b=\rho e^{\phi i}$ ($\rho > 1$) satisfies the equation:—

$$dw/dz = V_\infty e^{-\theta i}(1-e^{2\theta i}/z^2) + (\Gamma/2\pi i)(1/z) + (K/2\pi i)\{1/(z-\rho e^{\phi i}) - 1/(z-\{1/\rho\}e^{\phi i})\} \quad . \quad . \quad (1)$$

Assuming, as before, that the point of confluence of the streamlines is situated at the point $z=1$ of the cylinder, we have:—

$$V_\infty e^{-\theta i}(1-e^{2\theta i}) + \Gamma/2\pi i + (K/2\pi i)\{1/(1-\rho e^{\phi i}) - 1/(1-\{1/\rho\}e^{\phi i})\} = 0 \quad (2)$$

Eliminating Γ between (1) and (2), we find:—

$$dw/dz = [(z-1)/z]\,[V_\infty e^{-\theta i}(1+e^{2\theta i}/z) + (K/2\pi i)\{(1/\rho)e^{\phi i}/(1-\{1/\rho\}e^{\phi i})(z-\{1/\rho\}e^{\phi i}) - \rho e^{\phi i}/(1-\rho e^{\phi i})(z-\rho e^{\phi i})\}] \quad (3)$$

Whence, with § 2 (5), Part II:—

$$dw/d\zeta = [V_\infty e^{-\theta i}(1+e^{2\theta i}/z) + (K/2\pi i)\{(1/\rho)e^{\phi i}/(1-\{1/\rho\}e^{\phi i})(z-\{1/\rho\}e^{\phi i}) - \rho e^{\phi i}/(1-\rho e^{\phi i})(z-\rho e^{\phi i})\}] \times e^{\alpha i}[(z-1)e^{-\frac{1}{2}\alpha i} + (1-\epsilon)\cos\tfrac{1}{2}\alpha]^2/z\,[(z-1)e^{-\frac{1}{2}\alpha i} + 2(1-\epsilon)\cos\tfrac{1}{2}\alpha] \quad . \quad (4)$$

To obtain the general formula giving the velocity distribution $V_\lambda = |dw/d\zeta|$ over the surface of the aerofoil put $z=e^{\lambda i}$. Then

$$|V_\infty e^{-\theta i}(1+e^{2\theta i}/z) + (K/2\pi i)\{(1/\rho)e^{\phi i}/(1-\{1/\rho\}e^{\phi i})(z-\{1/\rho\}e^{\phi i}) - \rho e^{\phi i}/(1-\rho e^{\phi i})(z-\rho e^{\phi i})\}| = 2V_\infty\cos(\theta-\tfrac{1}{2}\lambda) - \{K\rho(\rho^2-1)\sin(\tfrac{1}{2}\lambda-\phi)\}/\{\pi(\rho^2+1-2\rho\cos\phi)(\rho^2+1-2\rho\cos(\phi-\lambda))\} \quad (5)$$

Further, since α is small:—

$$|(z-1)e^{-\frac{1}{2}\alpha i} + 2(1-\epsilon)\cos\tfrac{1}{2}\alpha|^2 \approx (1+\epsilon^2) - 2\epsilon\cos\lambda \quad . \quad . \quad (6)$$

And

$$|(z-1)e^{-\frac{1}{2}\alpha i} + 2(1-\epsilon)\cos\tfrac{1}{2}\alpha| \approx \{1+(1-2\epsilon)^2 + 2(1-2\epsilon)\cos\lambda\}^{\frac{1}{2}} \quad . \quad (7)$$

Thus we have finally

$$V_\lambda = [2V_\infty\cos(\theta-\tfrac{1}{2}\lambda) - \{K\rho(\rho^2-1)\sin(\tfrac{1}{2}\lambda-\phi)\}/\pi(\rho^2+1-2\rho\cos\phi)(\rho^2+1-2\rho\cos(\phi-\lambda))] \times (1+\epsilon^2-2\epsilon\cos\lambda)/\{1+(1-2\epsilon)^2+2(1-2\epsilon)\cos\lambda\}^{\frac{1}{2}} \quad . \quad . \quad (8)$$

The maximum velocity, occurring near the leading edge, will be obtained approximately with $\lambda=\pi$:—

$$V_{max} = [2V_\infty\sin\theta - \{K\rho(\rho^2-1)\cos\phi\}/\{\pi(\rho^4+1-2\rho^2\cos 2\phi)\}]\{(1+\epsilon)^2/2\epsilon\} \quad . \quad . \quad . \quad . \quad (9)$$

The velocity at the trailing edge is got for $\lambda=0$.

$$V_0 = [2V_\infty\cos\theta + \{K\rho(\rho^2-1)\sin\phi\}/\{\pi(\rho^2+1-2\rho\cos\phi)^2\}]\{(1-\epsilon)/2\} \quad (10)$$

For the equalisation of the velocities over the upper surface of the aerofoil, it is necessary to increase V_0 and decrease V_{max}, and this we achieve if, simultaneously :—

$$K \sin \phi > 0, \text{ and } K \cos \phi > 0 \quad . \quad . \quad . \quad . \quad (11)$$

In order to satisfy these inequalities, we must take ϕ in the first or the third quadrant according as K is $>$ or $<$ 0. The corresponding disposition of aerofoil and vortex for these two cases is shown in Figs. 13 and 14.

FIG. 13.

FIG. 14.

To realise the first in practice it would be necessary to place an inverted aerofoil over the upper surface of the main aerofoil in the vicinity of the trailing edge (Fig. 15). This arrangement, however, is little advantageous for the following reasons :—

FIG. 15.

1. The velocity in the neighbourhood of the trailing edge is comparatively small, and therefore the strength of the vortex K will be insignificant, and the resulting equalisation of the velocities feeble.
2. The force acting on the auxiliary aerofoil is directed downwards and so diminishes the lift on the slotted wing as a whole.

Observe that the second consideration is no longer applicable if the vortex K is not a member of the bound vortex system of the wing; and this, it seems, holds for vortices that trail from a slat. We shall return to the analysis of this question in another paper.

The second case may be satisfied by placing the auxiliary aerofoil near the leading edge either underneath ($\pi < \phi < 3\pi/2$) or in front of the main aerofoil ($\phi = \pi$). The latter is the more favourable position, since around the leading edge the velocity is greatest and therefore K can attain its maximum value. It is this which obviously leads to the adoption of the slat as a means of improving the properties of an aerofoil.

2. From the results of the preceding section the specific formulæ in the case of a slat are now easily obtained.

Putting $\phi = \pi$ in (9) and (10), we get for the maximum velocity and for the velocity at the trailing edge the respective expressions :—

$$V_{max} = [2 V_\infty \sin \theta + (K/\pi) \{ \rho/(\rho 2 - 1) \}] \{ (1+\epsilon)^2/2\epsilon \} \quad . \quad (1)$$

$$V_0 = V_\infty \cos \theta \, (1-\epsilon) \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Since, as shown in Part II, for breakaway at the trailing edge $V_{max}/V_0 = 1.2$, then we have the equation :—

$$\tan \theta + (K/2\pi V_\infty) \{ \rho/(\rho 2 - 1) \cos \theta \} = 1.2 \, (1-\epsilon)/(1+\epsilon)^2 \quad . \quad (3)$$

or, noting that $K < 0$ for a slat, and putting $|K| = I$:—

$$\tan \theta = 1.2 \, \epsilon \, (1-\epsilon)/(1+\epsilon)^2 + (I/2\pi \, V_\infty) \{ \rho/(\rho^2 - 1) \cos \theta \} \quad . \quad (4)$$

The corresponding limiting angle of attack θ_0 in the absence of the auxiliary aerofoil will be got from (4) on making $I = 0$. Thus

$$\tan \theta_0 = 1.2 \, \epsilon \, (1-\epsilon)/(1+\epsilon)^2 \quad . \quad . \quad . \quad . \quad (5)$$

Hence we get for the increase in θ due to the action of the slat the formula:—

$$\tan\theta-\tan\theta_0=(I/2\pi\ V_\infty)\ \{\ \rho/(\rho^2-1)\cos\theta\ \}$$

$$i.e.,\ \sin(\theta-\theta_0)=(I/2\pi\ V_\infty)\ \{\ \rho\cos\theta_0/(\rho^2-1)\ \} \quad . \quad . \quad (6)$$

or, approximately:—

$$\Delta\theta=\theta-\theta_0=(I/2\pi\ V_\infty)\ \{\ \rho\cos\theta_0/(\rho^2-1)\ \} \quad . \quad . \quad . \quad (7)$$

Consequently, in order to find $\Delta\theta$, it remains to determine I. We shall assume for simplicity that the slat takes the form of a small rectangular thin plate[19]

FIG. 16.

(Fig. 16). Then

$$I=\pi V_a b\sin\beta$$

where V_a is the velocity in the vicinity of the plate, b the chord of the plate and β its effective angle of attack.

Thus the problem reduces to finding the magnitude and direction of V_a.

3. For the determination of V_a we have formula § 1 (4). However, it must be remembered that a vortex cannot contribute a velocity to its own axis, and so, omitting the term

$$\rho e^{\varphi i}/(1-\rho e^{\varphi i})(z-\rho e^{\varphi i})$$

and putting $z=\rho e^{\pi i}$, *i.e.*, $-\rho$, we have for the magnitude of V_a:—

$$V_a=V_\infty\ |\ (e^{-\theta i}-e^{\theta i}/\rho)+K/\{\ 2\pi i V_\infty\ (\rho+1)\ (\rho-1/\rho)\ \}\ |$$

$$|-(\rho+1)\ e^{-\frac{1}{2}\alpha i}+(1-\epsilon)\cos\tfrac{1}{2}\alpha|^2/\rho\ |-(\rho+1)\ e^{-\frac{1}{2}\alpha i}+2\ (1-\epsilon)\cos\tfrac{1}{2}\alpha| \quad . \quad (1)$$

Consider the term

$$(K/2\pi i V_\infty)\ \{\ 1/(\rho+1)\ (\rho-1/\rho)\ \}$$

Taking its modulus, we get:—

$$|\ (K/2\pi i V_\infty)\ 1/(\rho+i)\ (\rho-1/\rho)\ |=\{\ |K|/2\pi\ (\rho-1/\rho)\ \}\ \{\ 1/V_\infty\ (\rho+1)\ \}$$

$$=v/V_\infty\ (\rho+1)$$

where v is the velocity induced at the axis of the vortex K by its image. In all analogous cases we may assume that the velocity induced by such vortices is small compared with that of the translational flow; consequently we may neglect the above term in (1).

Now

$$|\ e^{-\theta i}-e^{\theta i}/\rho\ |=\left[1+1/\rho^2-(2/\rho)\cos 2\theta\right]^{\frac{1}{2}} \quad . \quad . \quad . \quad (2)$$

Further, on account of the smallness of α:—

$$|-(\rho+1)\ e^{\frac{1}{2}\alpha i}+(1-\epsilon)\cos\tfrac{1}{2}\alpha|^2\approx(\rho+\epsilon)^2 \quad . \quad . \quad . \quad (3)$$

and

$$|-(\rho+1)\ e^{\alpha i}+2\ (1-\epsilon)\cos\tfrac{1}{2}\alpha|\approx(\rho-1+2\epsilon) \quad . \quad . \quad . \quad (4)$$

Hence (1) reduces to:—

$$V_a=\{\ V_\infty\ (\rho+\epsilon)^2/\rho\ (\rho-1+2\epsilon)\ \}\ :\ \{\ 1+1/\rho^2-(2/\rho)\cos 2\theta\ \}^{\frac{1}{2}} \quad . \quad (5)$$

---

[19] This does not involve any serious restriction of the generality since the general formula for the circulation about the auxiliary aerofoil is:

$$4\pi R V a\sin(\beta+\alpha'/2)$$

where R is the radius of the circle in the z-plane corresponding to the profile in the ζ-plane, and $2\alpha'$ the central angle of the skeleton.

Now, when α' is zero and ϵ' (thickness parameter of the slat) small, the chord b is equal approximately to $4R(1-\epsilon')$. The expression for the circulation may then be written:

$$\pi\{b/(1-\epsilon')\}V_a\sin\beta$$

which reduces to that in the text on neglecting ϵ'.

To find the direction of V_a, denote by μ the angle made by it with the x-axis. Then by general formulæ we have :—

$$V_a e^{-\mu i} = dw/d\zeta = (dw/dz)\,(dz/d\zeta)$$

i.e.,

$$V_a(\cos\mu - i\sin\mu) = V_\infty (e^{-\theta i} - e^{\theta i}/\rho)\,\{(\rho+\epsilon)^2/\rho(\rho-1+2\epsilon)\} \quad . \quad (6)$$

Whence on equating the real and imaginary parts in turn on both sides of (6) and eliminating V_a and V_∞ between the resulting equations, we get :—

$$\mu = \arctan\{[(\rho+1)/(\rho-1)]\tan\theta\} \quad . \quad . \quad . \quad (7)$$

Thus the formulæ (5) and (7) give the magnitude and direction of V_a sought.

4. We are now in a position to throw the formulæ defining the action of a slat into their final forms. Since $I = \pi V_a b \sin\beta$, then substituting for V_a from §3 (5), we get :—

$$I = \{\pi b \sin\beta V_\infty (\rho+\epsilon)^2/\rho(\rho-1+2\epsilon)\}\,\{1+1/\rho^2-(2/\rho)\cos 2\theta\}^{\frac{1}{2}} \quad (1)$$

where β is the effective angle of attack of the slat. If the inclination of the chord of the slat to the x-axis be denoted by γ, then we see that :—

$$\beta = \mu - \gamma \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where $\mu = \arctan\{[(\rho+1)/(\rho-1)]\tan\theta\}$.

Again, substituting (1) in §2 (7), we get the following expression for the increase in the limiting angle of attack :—

$$\Delta\theta = [\{b\sin\beta(\rho+\epsilon)^2\cos\theta_0\}/\{2(\rho^2-1)(\rho-1+2\epsilon)\}]\,\{1+1/\rho^2-(2/\rho)\cos 2\theta\}^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

A lower limit, $\Delta_0\theta$, to the corresponding increase in the limiting angle of attack will be obtained on putting $\theta = 0$.

Then

$$\Delta_0\theta = \{b\sin\beta(\rho+\epsilon)^2\cos\theta_0\}/\{2\rho(\rho+1)(\rho-1+2\epsilon)\} \quad . \quad (4)$$

Dividing (3) by (4) we have :—

$$\Delta\theta/\Delta_0\theta = k = \{1+4\rho\sin^2\theta/(\rho-1)^2\}^{\frac{1}{2}} \quad . \quad . \quad . \quad (5)$$

Since θ, as tests show, varies from 20° to 30°, then k is included within the limits, $[1+0.47\,\rho/(\rho-1)^2]^{\frac{1}{2}}$ and $[1+\rho/(\rho-1)^2]^{\frac{1}{2}}$. Tabulating these limits for various values of ρ, we have :—

ρ	$[1+0.47\rho/(\rho-1)^2]^{\frac{1}{2}}$	$[1+\rho/(\rho-1)^2]^{\frac{1}{2}}$	Mean Value for k
1.5	2	2.6	2.3
2	1.4	1.7	1.6
2.5	1.2	1.5	1.4

Hence, from (4) and (5) on neglecting the term ϵ^2 and taking $\cos\theta_0 = 1$ since θ_0 is usually $> 15°$, we obtain finally the approximate formula :—

$$\Delta\theta = \tfrac{1}{2}b\{\beta/(\rho+1)\}\{(\rho+2\epsilon)/(\rho-1+2\epsilon)\}k \quad . \quad . \quad (6)$$

where k is given by the table.

Here follow two numerical examples.

(i) $\theta_0 = 15°$, $\beta = 15°$, $\epsilon = 0.2$, $b = 0.7$, $\rho = 1.5$.

For this value of ρ the corresponding value of k obtained from the table is 2.3.
Substituting in (6), we get $\Delta\theta = (0.7 \times 15° \times 1.9 \times 2.3)/(2 \times 2.5 \times 0.9) = 10.2°$.
Hence the limiting angle of attack $= 15° + 10.2° = 25.2°$.

(ii) Same values as before for θ_0, β, ϵ and b, but $\rho = 2$.

Hence $k = 1.6$ and (6) gives $\Delta\theta = 4.8°$.
Hence the limiting angle of attack $= 15° + 4.8° = 19.8°$.

In these examples, the value of b is about 20 per cent. of the chord of the main aerofoil.

5. We shall now obtain the exact formula for $\Delta\theta$ corresponding to the approximate one of the preceding section, but which, however, is by reason of its complexity, less convenient for numerical calculation.

Substituting in §2 (6) the value of I given by §4 (1), we have:—

$$\sin \Delta\theta = \tfrac{1}{2} b \sin \beta \left[\{ (\rho+\epsilon)^2 \cos \theta_0 \} / \{ \rho (\rho - 1 + 2\epsilon)(\rho^2 - 1) \} \right] [\rho^2 + 1 - 2\rho \cos 2\theta]^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Denoting the whole expression outside the radical by A, we obtain after some reduction:—

$$\tan \Delta\theta = A \left[2A \sin 2\theta_0 \pm \{ (\rho-1)^2 + 4\rho \sin^2 \theta_0 - (\rho^2-1)^2 A^2 \}^{\frac{1}{2}} \right] / \left[1 - A^2 \{ (\rho-1)^2 + 4\rho \cos^2 \theta_0 \} \right] \quad (2)$$

As regards the choice of sign in the above, we note that when $\theta_0 = 0$

$$\tan \Delta\theta = \pm A (\rho - 1) / \{ 1 - (\rho+1)^2 A^2 \}^{\frac{1}{2}} \quad . \quad . \quad . \quad (3)$$

Hence we see that for a positive $\tan \Delta\theta$ (which alone corresponds with the conditions of the problem) it is necessary to take the sign plus.

So finally we have the following formula for $\Delta\theta$

$$\tan \Delta\theta = A \left[2A \sin 2\theta_0 + \{ (\rho-1)^2 + 4\rho \sin^2 \theta_0 - (\rho^2-1)^2 A^2 \}^{\frac{1}{2}} \right] / \left[1 - A^2 \{ (\rho-1)^2 + 4\rho \cos^2 \theta_0 \} \right]$$

where

$$A = \tfrac{1}{2} b \sin \beta \left[(\rho+\epsilon)^2 \cos \theta_0 \right] / \left[\rho (\rho - 1 + 2\epsilon)(\rho^2 - 1) \right] \quad . \quad . \quad (4)$$

We shall re-work the two numerical examples of the preceding section employing this formula:—

EXAMPLE 1.

$$\theta = 15^\circ, \ \beta = 15^\circ, \ \epsilon = 0.20, \ b = 0.7, \ \rho = 1.5.$$

Then

$$A = (0.7 \times 0.259 \times 1.7^2 \times 0.966) / (2 \times 1.5 \times 0.9 \times 1.25) = 0.150$$

$$\therefore \tan \Delta\theta = 0.150 \left[(2 \times .150 \times .5) + \{ .25 + (4 \times 1.5 \times .259^2) - 1.25^2 \times .150^2 \}^{\frac{1}{2}} \right] / \left[1 - .150^2 \{ .25 + (4 \times 1.5 \times .966^2) \} \right]$$

$$= 0.162$$

$$\text{or } \Delta\theta = 9^\circ \ 18'.$$

Thus the slat increases the limiting angle of attack from 15° without auxiliary aerofoil to 24° 18′. The result given by the approximate formula was 10.2° for $\Delta\theta$, which is close to the value just found.

EXAMPLE 2.

Same data as above but $\rho = 2$ in place of 1.5.

Then

$$A = (0.7 \times 0.259 \times 2.2^2 \times 0.966) / (2 \times 2 \times 1.4 \times 3) = 0.0505.$$

$$\therefore \tan \theta = 0.0505 \left[(2 \times .0505 \times .5) + \{ 1 + (4 \times 2 \times .259^2) - 3^2 \times .0505^2 \}^{\frac{1}{2}} \right] / \left[1 - .0505^2 \{ 1 + (4 \times 2 \times .966^2) \} \right]$$

$$= 0.0662$$

$$\text{or } \Delta\theta = 3^\circ \ 48'.$$

Consequently, in this case, the slat increases the limiting angle of attack from 15° to 18° 48′. The approximate formula gave $\Delta\theta = 4.8^\circ$.

In the preceding examples we chose the value of θ_0 arbitrarily, although in §4 of Part II was given the formula:—

$$\tan \theta_0 = 1.2 \ \epsilon \ (1 - \epsilon) / (1 + \epsilon)^2.$$

However, in addition to a correction for downwash, a correction would have to be applied to the value of θ_0 as given by this formula to allow for the effects described in §5 of Part II.

The numerical values for the increase of limiting angle obtained above are in good agreement with experiment.

6. The results obtained lead to the following constructive deductions. The action of a slat is to cause an equalisation of the velocities of flow on the upper

surface of the aerofoil. This equalisation is the better effected the greater the intensity of the bound vortex determined by either of the formulæ :—

$$I = \pi V_a b \sin \beta \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$I = \{ [\pi V_\infty b \sin \beta (\rho+\epsilon)^2] / [\rho (\rho - 1 + 2\epsilon)] \} \{ 1 + 1/\rho^2 - (2/\rho) \cos 2\theta \}^{\frac{1}{2}} \quad (2)$$

From (1) we have the following :—

(i) To obtain the greatest effectiveness from the slat it must be placed near the leading edge of the aerofoil where the velocity of flow is greatest.

From (2) it follows that by increasing ρ, I is diminished. Therefore

(ii) The slat should be placed as near to the aerofoil as possible, but yet so that there is left sufficient space between to allow of the former to function with a circulation about it.

(2) shows further that I increases with increase in the angle β. Therefore

(iii) The slat should be set at the greatest effective angle of attack for which it will work in a streamline flow.

The whole of the above approximate theory of the action of a slat is based on the replacement of the auxiliary aerofoil by a single bound vortex. Hence it follows that its chord " b " cannot be considered large as compared with the chord of the main aerofoil in the preceding formulæ. But from (2) it is obvious that the intensity of the vortex increases with increase in b. Therefore

(iv) The chord of the slat ought not to be very small in comparison with that of the main aerofoil.

From § 5 (4) it is seen that $\Delta\theta$ increases with θ_0. Consequently

(v) The main aerofoil itself ought to be of such a section as to sustain as large as possible an angle of attack without breakdown of flow.

We saw in Part II that for this it is desirable to choose aerofoils of fairly thick section, theory showing the most favourable value of ϵ to be 0.33.

Experimental data may be adduced in confirmation of these conclusions.

In illustration of one application of the results obtained, it may be mentioned that in the case of aerofoils of very thin section or possessing a sharp leading edge, the vortex roller formed at the leading edge, in addition to producing the thickening effect previously noted, also plays the rôle of a slat (Fig. 17), and therefore increases the angle of attack for which flow without breakdown is possible. It differs from an actual slat merely in being less stable and consequently less effective in equalising the velocities over the upper surface of the aerofoil.

FIG. 17.

FIG. 18.

7. All the preceding considerations may be applied conversely to the influence of the main aerofoil on the slat. For the deduction of the corresponding formula, we take § 1 (9) and (10). If the chord of the slat be taken, for example, perpendicular to the real axis, along which lies the chord of the main aerofoil (Fig. 18), then $\phi = -\pi/2$, and writing $K = \Gamma$, $\theta = \beta$, $V_\infty = V_a$, and $\epsilon = \epsilon'$, the formulæ (9) and (10) assume the respective forms :—

$$V_{max} = \{ 2V_a (1+\epsilon')^2 \sin \beta \} / 2\epsilon' \quad . \quad . \quad . \quad (1)$$

$$V_0 = [2V_a \cos \beta - \Gamma\rho (\rho^2 - 1)/\pi (\rho^2+1)^2] (1-\epsilon')/2 \quad . \quad . \quad (1')$$

Hence

$$V_0/V_{max} = [\cot \beta - \Gamma\rho (\rho^2-1)/2\pi V_a (\rho^2+1)^2 \sin \beta] \epsilon' (1-\epsilon')/(1+\epsilon')^2.$$

Since for breakaway the condition $V_{max}/V_0 = 1.2$ is fulfilled, then :—

$$\cot \beta = (1+\epsilon')^2/1.2\,\epsilon' (1-\epsilon') + \Gamma\rho (\rho^2-1)/2\pi V_a (\rho^2+1)^2 \sin \beta \quad . \quad (2)$$

Again, for breakaway in the absence of a supplementary vortex there is satisfied the condition :—

$$\tan \beta_0 = 1.2\, \epsilon' (1-\epsilon')/(1+\epsilon')^2$$

β_0 being the limiting angle of attack of the slat; then from (2) :—

$$\cot \beta - \cot \beta_0 = \Gamma\rho (\rho^2-1)/2\pi V_a (\rho^2+1)^2 \sin \beta$$

or

$$\sin (\beta-\beta_0) = -\Gamma\rho (\rho^2-1) \sin \beta_0 / 2\pi V_a (\rho^2+1)^2 \quad . \quad . \quad (3)$$

Further, since Γ is negative and, if α and ϵ be small, equal approximating to $-\pi V_\infty L/(1-\epsilon) \sin \theta$, where L is the chord of the main aerofoil and θ its angle of attack, then (3) becomes :—

$$\sin (\beta-\beta_0) = [V_\infty L\rho (\rho^2-1) \sin \theta \sin \beta_0]/[2V_a (\rho^2+1)^2 (1-\epsilon)] \quad . \quad (4)$$

For the determination of the velocity at the axis of the slat we may apply §3 (5), viz. :—

$$V_a = [V_\infty (\rho+\epsilon)^2/\rho (\rho-1+2\epsilon)]/[1+1/\rho^2-(2/\rho)\cos 2\theta]^{\frac{1}{2}} \quad . \quad (5)$$

wherein, nevertheless, it is necessary to make a correction for the change of scale. Since α and ϵ are assumed to be small, the radius of the circle on the z-plane corresponding to the profile of the main aerofoil is $L/4\,(1-\epsilon)$. In (5) this radius is unity. Hence in order to apply that formula to the present case we must replace ρ by the ratio :—

$$\rho_1/L/4\,(1-\epsilon) \text{ or } 4\,(1-\epsilon)\,\rho_1/L$$

where ρ_1 is a quantity characterising the distance of the slat from the main aerofoil. The distance measured to the centre of the latter is :—

$$\rho_1 + (L/4)^2/\rho_1$$

since if α and ϵ be small, the transition from the cylinder to the aerofoil is given approximately by :—

$$\zeta = z + (L/4)^2/z.$$

Under these circumstances we get :—

$$V_a = [V_\infty \{ 4\,(1-\epsilon)\,\rho_1/L+\epsilon \}^2 / \{ 4\,(1-\epsilon)\,\rho_1/L \} \{ 4\,(1-\epsilon)\,\rho_1/L-1+2\epsilon \}]$$
$$[1+\{ L/4\,(1-\epsilon)\,\rho_1 \}^2 - \{ L/2\,(1-\epsilon)\,\rho_1 \} \cos 2\theta]^{\frac{1}{2}} \quad . \quad . \quad (6)$$

Now, since we may assume that the vortex replacing the main aerofoil is situated approximately at a distance $L/3$ from the leading edge, then the distance between the axis of this vortex and that of the slat is given by (Fig. 19).

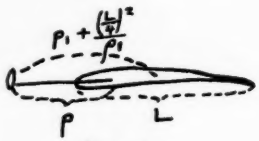

FIG. 19.

$$\rho = \rho_1 + (L/4)^2/\rho_1 - (L/2 - L/3) = \rho_1 + (L/4)^2/\rho_1 - L/6 \quad . \quad . \quad (7)$$

The formulæ (4), (6) and (7) solve the problem of the magnitude of the change in the limiting angle of attack of the slat due to the influence of the main aerofoil.

NUMERICAL EXAMPLE.

$$\theta = 25°,\ \beta_0 = 15°,\ \epsilon = 0.2,\ L = 10,\ \rho_1 = 4.70.$$

Then

$$V_a = [V_\infty \{ 1.50+0.2 \}^2/1.50 \{ 1.50-1+0.4 \}] [1+(1/1.50)^2-\cos 50°/0.75]^{\frac{1}{2}}$$
$$= 1.64\ V_\infty.$$

Also

$$\rho = 4.70 + 2.5^2/4.70 - 10/6 = 4.36.$$

Therefore

$$\sin(\beta-\beta_0)=(10\times 4.36\times 18\times 0.423\times 0.259)/(2\times 1.64\times 400\times 0.8)$$
$$=0.0820$$
$$i.e.,\ \beta-\beta_0=4^\circ\ 42'.$$

Thus the increase in the limiting angle is less than that in the case of the main aerofoil. This is explained by the unfavourable disposition of the vortex relative to the slat.

8. The formula giving the velocity distribution on the upper surface of the slat is obtained at once from § 1 (8), taking the slat chord to lie along the x-axis, and writing $\epsilon=\epsilon'$, $K=-|\Gamma|$.

The formula then becomes:—

$$V_\lambda=[2V_\infty\cos(\theta-\tfrac{1}{2}\lambda)$$
$$+\{|\Gamma|\rho(\rho^2-1)\sin(\tfrac{1}{2}\lambda-\phi)\}/\pi(\rho^2+1-2\rho\cos\phi)\{\rho^2+1-2\rho\cos(\phi-\lambda)\}]$$
$$\times[(1+\epsilon'^2-2\epsilon'\cos\lambda)/\{1+(1-2\epsilon')^2+2(1-2\epsilon')\cos\lambda\}^{\frac{1}{2}}] \quad . \quad (1)$$

Consider the velocities on the rear half of the upper surface of the slat, *i.e.*, when $\frac{1}{2}\lambda<\frac{1}{4}\pi$. Since θ is always $<\frac{1}{4}\pi$, then $\cos(\theta-\frac{1}{2}\lambda)>0$. Now if $\sin(\frac{1}{2}\lambda-\phi)$ be >0, then the second term in the square brackets of (1) shows that over the portion of the surface under consideration—due to the bound vortex Γ of the main aerofoil—the velocity is increased and the pressure consequently diminished, *i.e.*, the effect is of the same nature as that produced by the slat on the main aerofoil itself.

NUMERICAL EXAMPLE.

Let θ, angle of attack of slat, $=15^\circ$; $\phi=-60^\circ$; $\rho=4$; $\epsilon'=0$; $\epsilon=0.2$; angle of attack of main wing $=20^\circ$.

Then

$$|\Gamma|=\pi V_\infty L\sin 20^\circ/(1-0.2)=0.428\,\pi V_\infty L.$$

Hence substituting in (1) we get after some reduction:—

$$V_\lambda=V_\infty[\cos(15^\circ-\tfrac{1}{2}\lambda)/\cos\tfrac{1}{2}\lambda$$
$$+0.988\,L\sin(\tfrac{1}{2}\lambda+60^\circ)/\{17-8\cos(\lambda+60^\circ)\cos\tfrac{1}{2}\lambda\}] \quad . \quad (2)$$

Calculating V_λ for values of λ equal respectively to 0°, 45°, 90° and 135°, we obtain the following:—

$$V_{\lambda=0^\circ}=(0.966+0.0658\,L)\,V_\infty$$
$$V_{\lambda=45^\circ}=(1.073+0.0556\,L)\,V_\infty$$
$$V_{\lambda=90^\circ}=(1.225+0.0564\,L)\,V_\infty$$
$$V_{\lambda=135^\circ}=(1.590+0.0827\,L)\,V_\infty$$

On equating the expression for $V_{\lambda=0^\circ}$ and $V_{\lambda=90^\circ}$ we obtain the value of L for which the velocity distribution over the rear half of the upper surface of the slat is approximately constant. Thus

$$0.966+0.0658\,L=1.225+0.0564\,L$$

whence

$$L=27.6\text{ units.}$$

Since $\epsilon'=0$, the slat assumes the form of a thin plate of chord length four units; thus the chord of the main aerofoil is approximately seven times that of the auxiliary aerofoil. The pressure variation is sketched in Fig. 20.

Tests made at the C.A.H.I. on slats confirm the general nature of the curve obtained.

In a similar manner the pressure on the lower surface could be calculated, yet the result obtained through the above method would hardly be trustworthy, since the close proximity of the main aerofoil and the narrowness of the slot appreciably diminish the velocity there—a circumstance which cannot be discounted merely by replacing the main aerofoil by a vortex.

The preceding indicates the possibility of obtaining an approximately rectangular pressure distribution on the upper surface of an aerofoil. Such a distribution would have many advantages, and the question arises as to by what technical means would it be possible to secure this over an appreciable range of angles of attack.

FIG. 20.

It is probable that it could be achieved through the sucking under of the stream at the trailing edge. The same result could be attained by the insertion of vortices near the surface of the wing—a particular case of the latter method being the slotted wing analysed in the preceding pages.

ABSTRACTS AND NOTICES

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New Data on the Design of Elbows in Duct Systems. (L. Wirt, General Electric Review, Vol. 30, No. 6, June, 1927, pp. 286-296.) (U.S.A.)

The losses in elbows depend primarily on two design factors, designated by the author as Radius Ratio, R.1, and Aspect Ratio, R.2. R.1 is defined as R/D, where R = radius of inner bend of elbow and D = diameter of base duct measured in the same direction as R. The Aspect Ratio R.2 is defined as W/D, where W is the dimension of duct or elbow at right angles to D. Experiments show that for the normal design of elbows, small losses necessitate high values of R.1 and R.2. This is made clear in the following table, which applies to round bends delivering approximately 2,000 c. ft. of free air per minute.

R.1	R.2	% Loss of Velocity Head.
.6	1	130
2.8	1	30
.6	6	40
2.8	6	15

(A 130% loss means that the pressure loss through the elbow is 1.3 times the velocity head required to transmit the same flow through an orifice of the same section as the base of the elbow.)

If the corner of the bend away from the inner radius is made square, the losses in the bend are reduced by approximately 10%. This is due to the extra space enabling the air to form a " roller vortex " in the corner. In many cases consideration of space makes the use of bends with small values of R.1 and R.2 imperative. In these cases the losses can be considerably reduced if guide vanes are fitted. The author considers that it should be possible by this device to reduce the pressure losses in all practical cases to something of the order of 20/25% of the velocity head.

Electrically-operated Balance with Continuous Record of Large Wind Tunnel of the D.V.L. (M. Kramer, Z.V.D.I., Vol. 80, No. 6, 8th Feb., 1936, pp. 141-145. See also Aircraft Engineering, Vol. 8, No. 88, June, 1936, pp. 151-153.) (789 Germany.)

Electrically-operated steel yard balances have been on the market for some time. Their order of accuracy rarely exceeds 1/400 of the maximum load and is not as high as when hand operated.

The design developed by the D.V.L. overcomes this difficulty, the maximum error being 1/6000 of the maximum load, whilst most of the readings show double this accuracy.

Two contact laminæ are employed. When equilibrium is near, only one pair makes contact, but when further out of balance, both pairs come together and short circuit. A special eddy current brake fitted to the motor operates the jockey pulley.

A remote recording system can be employed to facilitate preliminary setting of the balance.

[For a description of the electric balance fitted to the N.P.L. compressed-air tunnel, see Aircraft Engineering, Vol. 5, Sept., 1933, pp. 200-2.]

The Theory of Turbulence—Transport of Momentum and Turbulence. (C. Ferrari, L'Aerotecnica, Vol. 15, No. 11/12, 1935, pp. 1,037-1,056.) (919 Italy.)

A useful summary of the present state of knowledge. Whilst the original concepts of Taylor and Prandtl break down if the streamlines exhibit considerable curvature, the statistical method as extended by Gebelein yields useful results.

Reference is also made to the recent theory of Mattioli, who introduces a term depending on the frequency of the intermingling.

37 references.

Interference of Wing and Fuselage from Tests of 209 Combinations in the N.A.C.A. Variable-Density Tunnel. (E. N. Jacobs and K. E. Ward, N.A.C.A. Report No. 540, 1935, p. 24.) (1032 U.S.A.)

Favourable interference effects are usually the result of drag saved by enclosing a considerable part of the wing surface within the fuselage. Marked adverse interference effects are associated with a breakdown of the flow near the wing-fuselage juncture. This phenomenon, referred to as the "interference burble," is a complicated one, dependent on the stability of the flow over the airfoil, the conditions at the wing-fuselage juncture, and the geometrical form of the air spaces at the juncture. Efficient airfoils of moderate thickness and low camber are most susceptible to such adverse interference. The interference burble does not necessarily affect the maximum lift coefficient.

Wind-Tunnel Investigation of the Aerodynamic Balancing of Upper-Surface Ailerons and Split Wings. (J. Wenzinger, N.A.C.A. Report No. 549, 1935.) (1033 U.S.A.)

As a result of the investigation, a balanced split flap was developed which required control forces about half those of the unbalanced split flap, when the balanced split flap was deflected to give approximately the same maximum lift.

Potential Flow About Arbitrary Biplane Wings Sections. (I. E. Garrick, N.A.C.A. Report No. 542, 1936.) (1097 U.S.A.)

A rigorous treatment is given of the problem of determining the two-dimensional potential flow around arbitrary biplane cellules. The flow problem is resolved by making use of the methods of conformal representation.

As an example of the numerical process, the pressure distribution over certain arrangements of the N.A.C.A. 4412 airfoil in biplane combinations is presented and compared with the monoplane pressure distribution.

The Bénard-Kármán Vortices Behind an Obstacle Moving in a Rectangular Channel. (P. Schwarz, Comp. Rend., Vol. 202, 1936, No. 12, pp. 1,021-1,024.) (1100 France.)

Two types of vortex streets are examined. In the first the vortices follow closely its walls of the channel, in the other there exists contraction or expansion.

Photographs are shown of these extremes and the experimental results are held

to confirm theoretical conclusion of the author published at the 3rd International Congress of Applied Mechanics (Stockholm), 1930.

On Certain Discontinuities in the Experimental Determination of Wing Polar Diagrams. (L. Sackmann, Comp. Rend., Vol. 202, 1936, No. 12, pp. 1,019-1,021.) (1101 France.)

As the angle of incidence increases, the polar diagram becomes unstable. The investigation of this region requires balance of small moment of inertia. Reference is made to experiments by Lafay (Publ. Scientifique et tech. du Ministere de l'air No. 9, 1935) carried out on a torsion balance.

This work has been extended by the author, and the presence of two well-defined regions above and below a certain critical angle of incidence (app. 12°) for a Joukowsky profile is established.

Simultaneous Registration of Wing Position and Air Pressure on a Flying Pigeon. (A. Magnan and H. Girard, Comp. Rend., Vol. 202, 1936, No. 12, pp. 1,109-1,111.) (1103 France.)

The bird was photographed with the Magnan high-speed camera (1,000 views/sec.). Air pressures near the wrist joint were recorded on the same film.

A sample photograph shows the alternation in air depression from upper to lower surface of the wing as the wing stroke changes from down to up.

The technique of the pressure measurements has been described in a previous number (C.R., Vol. 201, 1935, pp. 1145 and 1221).

A small static pressure hole is attached to the wing, the pressure being recorded through thin rubber tubing carried by the bird in flight.

The experiments will be continued to enable the pressure plotting to be extended over the whole wing surface.

A New Microscopic Method for Measuring the Viscosity of Liquid. (F. Hirata, Phys. Berichte, Vol. 17, No. 5, 1st Mar., 1936, p. 510.) (1124 Germany.)

The motion of small suspended particles is followed along the axis of a capillary. Satisfactory agreement with other methods is claimed.

The Motion of a Heavy Drop in an Acoustic Field. (S. W. Gorbatschew and A. B. Severny, Phys. Berichte, Vol. 17, No. 5, 1st Mar., 1936, p. 512.) (1126 Germany.)

The cragulation of two drops by sound waves cannot be explained by direct wave action. The authors consider the case of the drops vibrating as resonators under the action of surface tension, and this pulsation produces aerodynamic forces which, superposed in the acoustical field, may account for cragulation.

Boundary Interference of Partially Closed Wind Tunnels. (K. Kondo, Aer. Res. Inst. Tokio, Vol. 11, No. 137, March, 1936.) (1270 Japan.)

The author presents a comprehensive theory of wind tunnel interference with respect to partially rigid boundaries formed of circular arcs. General formulæ for the interference factor are determined for each type, together with the conditions for zero interference.

Experimental Investigation of the Problem of Surface Roughness. (H. Schlichting, Ing. Arch., Vol. 7, No. 1, February, 1936, pp. 1-34.) (1290 Germany.)

The experiments were carried out in a closed rectangular water channel, 170 × 40 m/m., length 3200 m/m. The top section (170 m/m. wide) is removable and can be fitted with various forms of projection (surface roughness). The other three sides of the channel are smooth.

The pressure drop along the rough plate was measured as well as the velocity distribution in the end section (delivery). From the latter the shear at the smooth wall can be calculated, and then the shear at the rough wall obtained by difference.

The results are given in a form rendering them readily applicable to channels and tubes of various sizes as well as to the case of a towed plate (ship hull resistance). It is shown that roughness of the plating is most deleterious if present near the prow of the ship. Similar degree of roughness extending over the same area near the stern produces only half the effect on the resistance.

Twenty references.

The Influence of Shape of Static Pressure Hole on the Recorded Pressure. (A. Miyadzu, Ing. Arch., Vol. VII, No. 1, Feb., 1936, pp. 35-41.) (1291 Germany.)

The experiments were carried out in a water channel of square section (27 m/m.) 2340 m/m. long. Five static pressure holes were fitted at distances of 150 m/m. If all five holes are alike, the pressure drop as registered in the usual water manometer is uniform. By having the central hole of different dimensions to the four others, this uniformity was generally disturbed, the manometer of the central hole reading an amount Δh above or below the pressure gradient as given by the other holes.

The following conclusions were reached:—

1. For a given hole $\Delta h/U^2$=constant. (U=average velocity in pipe).
2. $\Delta h/U^2$ increases linearly with diameter of hole over the experimental range. (.1 to 4 m/m.)
3. Provided length of hole l exceeds 2 diameters, further increase of l has no effect on $\Delta h/U^2$. Shorter holes are very sensitive to l/d ratio and not recommended.
4. As is to be expected, inclination of bore hole as well as orientation relative to stream produce marked effects.

Speaking generally, the experiments demonstrate the extreme difficulty of measuring static pressure accurately.

Surface Waves Produced by an Oscillatory Body. (M. Schuler, Z.A.M.M., Vol. 16, No. 2, April, 1936, pp. 65-72.) (1294 Germany.)

An infinite solid of constant cross section executes vertical oscillations by which it dips periodically into water. The research deals with the waves produced by this movement of a body of rectangular section. The loss of energy is measured by the amplitude of the progressive waves at infinity. The latter is proportional to the amplitude of the oscillatory movement of the body, and also depends on its frequency and the depth of immersion. The results of the experiments are compared with the results of computations by various approximate methods.

Five references.

Vibration of an Infinite Elliptic Cylinder in a Viscous Liquid. (M. Roy, Z.A.M.M., Vol. 16, No. 2, April, 1936, pp. 99-108.) (1296 Germany.)

The case of slow periodic motion (two-dimensional) is considered. For the circular cylinder the differential equations of the Mathieu type are accurately soluble in terms of Bessel and elementary functions. For the elliptic case an approximate solution is obtained for the pressure distribution and force per unit length.

Resistance Due to Acceleration of Bodies Moving Rectilinearly in a Perfect Fluid. (St. Neumark, Z.A.M.M., Vol. 16, No. 2, April, 1936, pp. 117-120.) (1298 Germany.)

When a body undergoes acceleration in a fluid, the resistance experienced is not the same as when the fluid undergoes acceleration relative to the body.

The difference is equal to the inertia force of the fluid displaced by the body. The paper deals with several applications of this theorem.

A Simple Solution of the Flat Plate Problem of Skin Friction and Heat Transfer. (N. A. V. Piercy and J. H. Preston, Phil. Mag., Vol. 21, No. 143, May, 1936, pp. 995-1,005.) (1347 Great Britain.)

A new solution is obtained of the flat plate problem of skin friction and heat transfer under steady conditions at large Reynolds numbers. The method employed is one of successive approximation, and the several results of the past thirty-five years on which the theory of the subject rests are reproduced as steps. In contrast with earlier investigations, the analysis is throughout simple and the need of computation slight. With no numerical work at all it is possible to attain within 3 per cent. of the final results of either more exact analysis or mean experiment. It is hoped that the method will find other uses in hydrodynamics. Its theory is not discussed from a general point of view, but convergence is shown to be so rapid in the present application that the sixth approximation approaches the correct analytical result within 0.25 per cent.

Turbulent Jet Expansion. (E. Förthmann, Ing. Arch., Vol. 5, No. 1, 1934, pp. 42-53, translated as N.A.C.A. Tech. Memo. No. 789, March, 1936.) (1569 Germany.)

The investigation described in this report refers to the velocity distribution in an open, in a partially open, and in a partially expanding jet. The open-jet observations reveal minor systematic discrepancies from Tollmien's theoretical velocity distribution. The shearing-stress distribution for the partially open jet was determined. The value derived for the ratio of mixing distance to jet width was found to be in close agreement with the corresponding value for the open-jet boundary. The streamline pattern in a partially expanding channel was obtained from the observed velocity distribution and plotted, after which the distribution of the mixing distance for this case was also ascertained.

Capillary Flow Starting from Rest.—Investigation of Initial Period. (A. Grumbach, Comp. Rend., Vol. 202, No. 20, 18th May, 1936, pp. 1,653-1,654.) (1588 France.)

The author investigates laminar flow in a vertical tube under the action of gravity. Steady conditions are reached rapidly. Thus in the case of water flowing through a tube 0.5 mm. diameter, volume per second in terms of t (time from start in seconds) is given by

$$V = (\pi g r^4/8\mu)\ (1 - 0.03\ e^{-92\ t})$$

where r = radius of tube.

μ = coefficient of viscosity.

On the Stability Problems in Hydrodynamics. (C. L. Pekeris, Proc. Camb. Phil. Soc., Vol. 32, Part 1, January, 1936, pp. 55-66.) (1591 Great Britain.)

So far, three cases of the breakdown of laminar flow have been found amenable to mathematical treatment:—

1. Rotary motion of a fluid between concentric cyclinders.
2. Linear laminar flow between parallel planes in relative motion.
3. Parabolic laminar flow between fixed parallel plates.

Case 1 has been solved successfully by G. I. Taylor and the conclusions verified by experiments (Phil. Trans. A, 223 (1923), p. 289). From the work of Southwell and Chitty (Phil. Trans. A., 229 (1930), p. 205) it appears that Case 2 is stable for first order disturbances. Very little has so far been done in Case 3, although it is known from the work of Rayleigh that the flow must be stable in the limit of vanishing R (Reynolds number). The author has built up a solution for finite value of R from this, using Schrödinger's perturbation theory. If laminar flow

is in the direction of the x axis and is bounded by the plane $y = \pm h$ and if the stream function of the disturbance is of the form $f(y) \exp i\alpha (cu/h\, t - x/h)$ it is shown that the flow is stable for values of R less than the smaller of the quantities 2α and α^3.

(See also in the same journal " The Stability of Viscous Fluid Flow under Pressure between Parallel Planes," by S. Goldstein, pp. 40-54, whose conclusions are in agreement with those of Pekeris.)

The Gliding of a Plate on a Stream of Finite Depth.—Part II. (A. E. Green, Proc. Camb. Phil. Soc., Vol. 32, Part 1, January, 1936, pp. 67-85.) (1592 Great Britain.) (For Abstract of Part I, see " Abstracts and Notices," No. 37, March, 1936, Item No. 19.)

In Part 1 the author considered the case of a plate infinite in one direction. The present case deals with a plate of finite length. As would be expected for a given depth of stream and a given height of the trailing edge above the bed of the stream, the value of the lift increases with length of plate, reaching a maximum for the infinite plate. The values obtained link up satisfactorily with the well-known Rayleigh solution for complete immersion in an infinite fluid.

Influence Lines for the Wave Resistance of Ships.—I. (E. Hogner, Proc. Roy. Soc., Vol. 155, No. 885, 2nd June, 1936, pp. 292-301.) (1623 Great Britain.)

The recently proposed " interpolation formula " for the wave resistance of ships and, as a special case of it, the Michell formula are used for constructing " influence lines " for the wave resistance. The influence lines can be drawn for every section of the hull and indicate the increase in wave resistance for an infinitesimal unit increase of displacement, altering the latter at one point or symmetrically at one point on each side of the ship. The influence lines thus give a survey of how to modify the ship's form in order to reduce the wave resistance and they give means to calculate the alteration of the latter by a projected change of form.

Breaking Up of a Drop of Viscous Liquid Immersed in Another Viscous Fluid which is Extending at a Uniform Rate. (S. Tomotika, Proc. Roy. Soc., Vol. 153, No. 879, 1st Jan., 1936, pp. 302-318.) (1626 Great Britain.)

The writer discusses the mode of breaking up of a drop of one viscous liquid immersed in another viscous fluid which is extending at a uniform rate in one direction and contracting symmetrically in all directions at right angles to this.

Taylor observed that when the rate of distortion in the outer fluid reaches a certain value, the drop becomes unstable and stretches out into a thin thread.

The present paper explains in a satisfactory manner why the thread does not break up immediately into drops.

On the Calculation of the Velocity and Temperature Distributions for Flow Along a Flat Plate. (L. Howarth, Proc. Roy. Soc., Vol. 154, No. 882, 1st April, 1936, pp. 364-377.) (1631 Great Britain.)

Kármán's logarithmic formula for the universal velocity distribution for the turbulent flow near a plane boundary cannot, on any theoretical grounds, be expected to hold throughout the turbulent boundary layer along a flat plate. The experimental agreement shown must be accidental.

Calculations have been made in order to obtain an expression for the velocity distribution on a theoretical basis. The two-dimensional vorticity and momentum transport theories are used. The mixing length l causes some difficulty. Calculations in which either the form arrived at by Kármán from the hypothesis of dynamical similarity or that used by Prandtl (l a constant multiple of the distance from the wall) are definitely to be desired.

The temperature distribution in the boundary layer of a heated plate was also calculated. On the momentum theory this is identical with the velocity distribution; it is shown that, on the vorticity theory, the two distributions are in as close agreement as the somewhat scattered experimental points.

On the Action of Viscosity in Increasing the Ratio of a Vortex Street. (S. G. Hooker, Proc. Roy. Soc., Vol. 154, No. 881, 2nd Mar., 1936, pp. 67-89.) (1635 Great Britain.)

The paper considers the effect of viscosity upon the distribution of vorticity and velocity in a Kármán vortex street. Although the centres of vorticity remain fixed at the original position, the centre of rotation of the eddies (as they would be estimated by eye) move outwards away from the axis of the street, thus causing an apparent increase in the spacing ratio. Photographs of a vortex street formed in water behind an elliptic cylinder are reproduced. From the measured velocity distribution an estimate of the age of the eddies is formed. This enables the amount of widening due to viscosity to be calculated. Comparison with experiment is satisfactory and indicates that the arrangement of vorticity centres obeys the Kármán distribution closely.

The Caproni Ca 135 (*Day and Night Bomber Monoplane*). (Figures supplied by Makers.) (—— Italy.)

Construction:—Wooden wings with plywood covering; fuselage steel, partly covered dural and partly fabric. Retractable undercarriage and Z.A.P.P. flaps are fitted. Factor of safety, 7.5.

Weight:—Total, 16,300 lbs. Useful, 6,300 lbs. (crew of four, 1,100lb. bombs, 1,850 lbs. of petrol).

Range:—At 15,000 feet, 1,200 miles.

Speed:—At 16,000 feet, 250 m.p.h. Landing, 65 m.p.h.

Ceiling:—26,000 feet.

Armament (defensive):—1 machine gun 7.7 calibre forward; 1 machine gun 12.7 calibre in retractable turret firing rear; 1 machine gun 12.7 calibre in retractable turret firing downwards.

Latécoére Flying Boats. (L'Intransigeant, 8th May, 1936.) (—— France.)

Owing to lack of strict technical inspection, the Latécoére 301 differs from its prototype 300. The structure possesses excessive elasticity which causes deformation of the rudder.

In bad weather, flexibility of the wings causes inversion of controls, which has led to fatal accidents.

As a result, the only machines available to Air France for its bi-weekly air mail service to South America are the four-engined troop carrier "Centaure" and the flying boat "Ville de Santiago."

Research on Model Airscrews. (G. P. Douglas, Airc. Eng., Vol. 8, No. 85, March, 1936, pp. 73-78.) (1030 Great Britain.)

This paper read before the 5th Volta Conference in Rome (September, 1935) is a review of work previously published in a series of R. & M.s, to which reference is made.

The main conclusions reached are:—

1. The Glauert formula gives a good approximation to the initial rise in the value of the lift coefficient with increase in tip speed.

   Depending on profile, experiment shows serious departure from the formula as the tip speed reaches 0.7 to 0.8 of the velocity of sound, whilst the Glauert formula shows further increase—in practice there is a serious drop. This coincides with a sudden rise in the drag coefficient.
2. For high-speed operation, blade sections shall be as thin as possible.

3. The scale effect on the characteristics of these models (2ft. diameter) appears to be small. A 50 per cent. increase in scale delays the compressibility stall about .02 of the velocity of sound.
4. There is no sudden increase in the noise gradient as the compressibility stall is reached. The quality of the noise becomes, however, very penetrating and unpleasant.

Automatic Stabilisation, Part IV—Course Setting. (F. Haus, L'Aeron., No. 202, March, 1936, pp. 29-37.) (1073 France.)

Automatic stabilisation consists essentially of two parts—a method of detecting deviation from a set course and a servo motor moving the controls in the requisite manner. The detector is generally gyroscopic and various standard types are described. The servo motor is now commonly operated with compressed air or oil. By this means the pilot can override the Robot by the simple means of by-passing oil or air pressure.

The development of Robot control requires further study of the interaction of aileron control on course stability.

On the Optimum Tonnage of Large Transport Machines or Bombers. (L. Breguet, Comp. Rend., Vol. 202, No. 12, 1936, pp. 1,024-1,026.) (1104 France.)

If

P = total gross weight of aircraft ready to take off,
P_s = weight of structure = αP,
P_m = weight of power plant = βP,
P_f = weight of fuel and tanks = γP,
P_c = weight of crew and equipment,
P_p = pay load,

the optimum tonnage is defined as the one making P_p/P a max.

The author develops an expression for P_p/P in terms of α and concludes that with a fixed value for P_c of 1300 kg. (crew of five and equipment) the optimum tonnage for a transatlantic flight is of the order of 20 tons.

Larger machines may, however, be justified from the point of view of increased comfort, seaworthiness or added security by multiplying the number of power units.

Ziegler-Turbo Wing. (Flugsport, Vol. 28, No. 7, 1st April, 1936, pp. 138-143.) (1109 Germany.)

The wing is fitted with passages leading from the pressure to the suction side. These passages are controlled by automatic flaps. Increased lift when starting is claimed.

The Nature of the Torsion-Aileron Wing Flutter as Revealed by Analytical Experiments. (K. Sezawa and K. Kubo, Aer. Res. Inst. Tokio, Vol. 11, No. 136, February, 1936.) (1119 Japan.)

The object of the present investigation was the study by means of model experiments of the torsion-aileron flutter of a wing. A mathematical investigation was also carried out. Flutter appears to be due, partly to instability in the free oscillations of the wing and partly to resonant vibrations. These are particularly liable to occur at a wind velocity corresponding to neutral stability of the free oscillations.

Full-Scale Wind-Tunnel Tests to Determine a Satisfactory Location for a Service Pitot-Static Tube on a Low-Wing Monoplane. (J. F. Parsons, N.A.C.A. Tech. Note No. 561, March, 1936.) (1170 U.S.A.)

Surveys of the air flow over the upper surface of four different airfoils were made in the full-scale wind tunnel to determine a satisfactory location for a fixed

pitot-static tube on a low-wing monoplane. The selection was based on interference errors of less than 5 per cent., and on considerations of structural and ground-handling problems. The most satisfactory location on the airfoils without flaps that were investigated was 10 per cent. of the chord aft and 25 per cent. of the chord above the trailing edge of a section approximately 40 per cent. of the semi-span inboard of the wing-tip. No satisfactory location was found near the wing when the flaps were deflected.

Experiments with Stabilising Fins in V Form (Type Budig, Rudliki). (Flugsport, Vol. 28, No. 9, 29th April, 1936, pp. 187-188.) (1350 Germany.)

The model experiments were carried out on a Mauboussin low-wing machine. No rudder is fitted, aileron control only being used.

The experiments showed reduced stability for small and increased stability for large deflections.

The new tail unit has smaller weight and resistance than the standard, but more experiments are required before an opinion as to utility can be given.

A full-scale machine fitted with the device is illustrated.

Procedure for Determining Speed and Climbing Performance of Airships. (F. L. Thompson, N.A.C.A. Tech. Note No. 564, April, 1936.) (1469 U.S.A.)

The procedure for obtaining air-speed and rate-of-climb measurements in performance tests of airships is described. Two methods of obtaining speed measurements, one by means of instruments in the airship and the other by flight over a measured ground course, are explained. Instruments, their calibrations, necessary correction factors, observations, and calculations are detailed for each method, and also for the rate-of-climb tests.

A method of correction for the effect on density of moist air and a description of other methods of speed-course testing are appended.

Airships for Naval Service. (Dr. W. Hovgaard, U.S. Nav. Inst. Proc., Vol. 62, No. 397, March, 1936, pp. 362-370.) (1543 U.S.A.)

Airships are considered invaluable for certain strategical duties such as coastal patrol, convoy escort, mine-field and submarine detection. Designed as an aeroplane carrier, it possesses extreme range of reconnoitring. Moreover, even in bad weather, aeroplanes can always be launched and recovered from an airship, which is certainly not the case with normal aeroplane carriers. To cover efficiently all these duties, airships of various sizes are required, ranging from small non-rigid blimps to large rigids of six million cubic feet and over.

Wind-Tunnel Tests of 10ft. Diameter Autogiro Rotors. (J. B. Wheatley and C. Bioletti, N.A.C.A. Tech. Report No. 552, 1936.) (1618 U.S.A.)

A series of 10ft. diameter autogiro rotor models were tested in the N.A.C.A. 20ft. wind tunnel. The results indicate the possibility of obtaining further improvements in the L/D by using thinner airfoil sections and by employing tapered blades with a tip chord smaller than the root chord. The optimum values of L/D obtained so far are of the order of 6. Similar tests carried out on a gyroplane model (N.A.C.A. Tech. Report No. 536, and Abstract No. 120 of "Abstracts & Notices," No. 37, March, 1936) gave maximum L/D of the order of 5.

Tests of N.A.C.A. Airfoils in the Variable-Density Wind Channel. (E. N. Jacobs and R. M. Pinkerton, N.A.C.A. Tech. Note No. 567, May, 1936.) (1637 U.S.A.)

The results of tests of six airfoils having the N.A.C.A. 230 mean line and varying in thickness from 0.06 c. to 0.21 c. are presented. These results agree

with previous findings in showing that aerodynamically the best section is one of moderate thickness. The data are of value mainly in connection with the design of tapered wings having sections based on the N.A.C.A. 230 mean line.

Calculated Effect of Various Types of Flap on Take-off Over Obstacles. (J. W. Wetmore, N.A.C.A. Tech. Note No. 568, May, 1936.) (1638 U.S.A.)

The results indicate that substantial reductions in take-off distance are possible through the use of flaps, provided that the proper flap angle corresponding to a given set of conditions is used. The best flap angle for taking off varies inversely as power loading and, to a much smaller extent, inversely with wing loading. Apparently, the best take-off characteristics are provided by the type of device in which the flap forms an extension to the main wing as in the case of the Fowler wing and the external airfoil flap.

A Retractable Planing Bottom for Flying Boats. (Aeroplane, Vol. 50, No. 1,307, 10th June, 1936, p. 744.) (1647 Great Britain.)

Details are given concerning British Patent No. 433925 (Major Rennie). The planing bottom is separated from the rest of the hull and mounted on links so that it can project below the main position of the hull as long as the craft is on the water. In the air the pontoon is withdrawn into the hull. Two advantages are claimed:—

1. Adequate propeller clearance in the case of wing engines is provided for a smaller height of boat structure.
2. The conflicting requirements of take-off and flying level are more easily dealt with.

Gyroscope or Wind Vane. (Les Ailes, No. 782, 11th June, 1936, p. 4.) (1659 France.)

The French Government have purchased exclusive rights from M. Constantin of his automatic pilot actuated by wind vanes

It is claimed that this system is simpler than the gyroscope. It is specially suitable for flights at low altitude and low speed.

Gyroscopic control under such conditions is unsatisfactory.

The American Weick Safety Plane. (Les Ailes, No. 782, 11th June, 1936, p. 4.) (1660 Great Britain.)

This machine is fitted with a novel landing carriage, capable of automatic orientation. It is claimed that cross-wind landing can be carried out safely.

The Mastery of the Sea. (P. Barjot, Riv. Aeron., Vol. 11, No. 10, Oct., 1935, pp. 81-84, and Revue du Ministère de L'Air, No. 6, 1935, pp. 692-698.) (—— Italy.)

In the past, the mastery of the sea could be maintained by a powerful fleet concentrated at certain bases within striking distance. Only these bases were defended against naval attack, the rest of the coast being undefended. The advent of aircraft has modified this procedure as far as narrow seas are concerned. Only in the case of oceans situated at considerable distances from the home waters will mastery still depend on a fleet of large surface ships. In the case of narrow seas, the mastery will go to the nation possessing the most powerful aircraft. Operations in such waters will no longer consist of fleet actions, but will be entirely of an aerial character, viz., raids on bases and patrols. It is thus essential that a coast line bordering a narrow sea be plentifully provided with anti-aircraft batteries and high-speed chasing squadrons, stationed to protect all vulnerable bases.

Experiments with Fragmentation Bombs. (O. G. Alberti, Riv. Aeron., Vol. 11, No. 10, Oct., 1935, pp. 63-65.) (—— Italy.)

The knowledge of the disruptive effect of various types of bombs is very limited. Experiments in which the stationary bomb is exploded in close proximity to the objective are apt to be misleading and full-scale experiments (dropping bombs) require large targets. The author proposes to drop bombs from a ropeway bridging a narrow valley at an altitude of 600/700 metres; such valleys are available in Italy. This gives a normal striking velocity of the bomb of the order of 100m./sec., which can be augmented by launching the bomb by means of a catapult. The following advantages are claimed for the scheme:—

(a) In the case of vertical drop a very restricted target can be employed.
(b) A large number of bombs can be dropped in quick succession.
(c) Important ballistic data can be gathered (vertical drop or horizontal catapulting).

The damage done by the bomb can be tested on simple elements or complete structures. The following points are of special interest:—

(1) Stability of structure hit.
(2) Action of internal and external explosions on target.
(3) Effect of air and ground vibration.

The estimated cost of such a test plant is 200,000 lire.

The Possibilities of Dive Bombing. (A. Vanin, Riv. Aeron., Vol. 11, No. 12, Dec., 1935, pp. 424-432.) (589 Italy.)

The author considers the case of diving from 1,000 m. at 70 degrees and releasing the bomb at 500 m. During the dive, the engine speed is kept constant and equal to that during level flight. The trajectory of the bomb, allowing for air resistance, is worked out. The point of impact and the intersection of the direction of dive with the ground differ by less than 30 metres. This displacement can be easily allowed for by a simple sight similar to that fitted to the front stationary machine gun. The high stresses to which the machine is subjected on pulling out, limit the form of attack to small aircraft possessing the necessary factors of safety. Only small bombs can be carried (total bomb load 300 lbs. in units of 1 to 6 lbs.) and thus only weakly-armoured targets can be attacked.

The method is considered specially useful in colonial warfare.

Fixing the Position of Aircraft at a Given Instant. Measurement of Speed and Application to Bombing Practice (concluded). (Capt. Vauzou, Rev. de l'Arm de l'Air, No. 80, March, 1936, pp. 313-328.) (896 France.) (For Part 1, see "Abstracts and Notices," No. 37, March, 1936, Item 47.)

The author describes how standard photographic survey equipment can be modified to obtain photographs from the ground of aircraft attacking a target (in this case the camera). The camera uses plates 28 × 24 cm., arranged horizontally. Under these conditions the field of view makes an angle averaging 22 degrees with the vertical. The position of smoke release must therefore make an angle of this order, and this necessarily restricts the method to a certain minimum height (say 6,000 feet) or to artificially reduced flying speeds. This is not considered detrimental from a training point of view.

The author has developed a tabular method of noting the experimental results with the object of saving time and gaining clarity. The final sheet gives the accuracy of the bomber in question, which is filed for record and training purposes. (For further particulars of this, see Translation No. 317.)

Fighting Technique for Recovery from Spins. (W. H. McAvoy, N.A.C.A. Tech. Note No. 555, Feb., 1936.) (924 U.S.A.)

Slow and cautious movement of the controls is to be avoided and brisk operation resorted to.

The following procedure is recommended:—

1. Ailerons neutral throughout.
2. Briskly move rudder to a position full against the spin.
3. After an appreciable lapse of time (at least ½ additional turn) briskly move elevator to the full down position.
4. Hold these positions till recovery is effected.

Various emergency measures are also described.

It has been reported that, as a result of the pilot standing up in his seat, the aeroplane recovered. This is probably due to free controls having a beneficial effect.

Normal and Dive Bombing—Relative Advantages. (L'Aerophile, No. 3, March, 1936, pp. 60-61.) (1026 France.)

Normal bombing from high altitudes produces great terminal speeds and thus good penetration. On the other hand, individual aiming is difficult. Dive bombing is limited to low altitude and suffers from insufficient penetration, although the aiming is probably good. The author on the whole favours normal bombing, but considers an increase in dive bombing speeds (such as rocket propulsion attached to the bombs) may alter the conclusions.

What Chance Has Pursuit? (C. Rougeron, Aviation, Vol. 35, No. 4, April, 1936, pp. 11-14.) (1278 U.S.A.)

Provided there is a sufficient margin in speed, the faster single-seater pursuit is favoured against the heavy bomber flying in mass formation.

The German Air Force in 1936. (P. Naquet, l'Aérophile, Vol. 44, No. 4, p. 76, April, 1936.) (1313 France.)

The object of the German Air Ministry under General Goering was to establish 93 squadrons (each of 15 machines) by the end of 1935.

By that date only 61 squadrons were completed, in the proportion:—

50 per cent. bombers.
25 per cent. reconnaissance.
25 per cent. pursuit.

It is now stated that the original estimate (approximately 2,000 machines) will be reached in October of this year, and 150 squadrons will be established by the end of 1937.

The French author expresses doubt as to Germany being capable of producing the necessary engines in the time, since it took France four years to definitely establish the Hispano Suiza 12 XI.

In conclusion, the opinion is expressed that the German Air Fleet is definitely inferior to that of France, and likely to be so for some time.

Experiments with Oerliken Cannon Fitted to PZL P24 Single-Seater. (Flugsport, Vol. 28, No. 8, 15th April, 1936, p. 173.) (1354 Germany.)

The wing position of the gun is preferred to an installation in close proximity to the engine on account of fire danger. Two guns are recommended for the sake of reliability, and a high-speed machine gun is also provided.

(Available as Translation No. 323.)

Strength of Italian Air Fleet. (P. Naquet, L'Aérophile, Vol. 44, No. 5, May, 1936, p. 105.) (1577 France.) (Available as Translation No. 320.)

The Italian Air Force is in a state of reorganisation. In July, 1934, 1,550 million francs were voted, complete modernisation to be effected in five years. It has since been decided to speed up the work and complete in three years.

First attention was paid to fighters and four squadrons equipped with Fiat CR 30, and CR 32 are now available. These have a maximum speed of 360 km./hour and are armed with two machine guns.

For heavy bombers only one type has been chosen (S81) and 130 of these are in course of delivery. The Navy will shortly be supplied with seaplane Z 501 (maximum speed 200 km./hour, one ton of explosives, range 1,000 km.).

The author concludes that the Italian Fleet is inferior in quality and quantity to the French.

Counting new types in course of development, this inferiority is considered assured for several years to come.

Aerial Bombing. (M. Lenoir, L'Aérophile, Vol. 44, No. 5, May, 1936, p. 106.) (1578 France.)

In the case of attack on ships, horizontal launching of the bomb is favoured rather than dive bombing. The extra kinetic energy due to release at high altitudes is insignificant compared with the energy of the explosive, and by dropping bombs in series at low altitudes the chances of damaging the ship are greatly increased.

Aerial Bombardment at Sea. (Chief Engineer Rougeron, Rev. de l'Arm de l'Air, No. 82, May, 1936, pp. 483-495.) (1674 France.)

This is the third concluding part of a series of articles (previous instalments, see Revue des Forces Aèriennes, April, 1933, and Rev. de l'Arm de l'Air, November, 1934). Ultimately ships have to come to port, and this is where they should be attacked by aircraft. The author favours the use of winged bombs. These can be launched at a considerable distance from the target. Devices are easily fitted so that the wings are easily shed on impact with water, a lighted fuse causing subsequent under-water propulsion. In this way the zone of possible damage is increased considerably over that of the normal bomb.

Unlike the submarine torpedo, such a device is robust and cheap.

Silencers for Aircraft Engines. (Flight, Vol. 29, No. 1,420, 12th March, 1936, pp. 272-276.) (928 Great Britain.)

The exhaust noise of an engine is concentrated in two main frequency bands separated by a wide band of low intensity. The low frequency band ranges from approximately 50 to 700 cycles/sec., whilst the other band extends from 3,000 to 9,000 cycles/sec.

In the R.A.E. silencer, these two sources of disturbance are dealt with separately, the gases passing first through two high frequency filters placed in series before entering a large expansion chamber from which they are discharged into the atmosphere. The filters essentially consist of three concentric tubes. The gas passes through the inner one, which is perforated. The second tube is also perforated and a series of transverse partitions divide the concentric space between the two tubes. The outer or third tube acts as a chamber, but is sealed with regard to the atmosphere. A silencer of this type for a 500 h.p. engine weighs approximately 40 lbs. and exerts a back pressure from 0.7 to 3 inches of mercury. The noise reduction in the test bench (at 50ft.) amounted to approximately 24 decibels, whilst the noise reduction on the ground with the aircraft flying at 500 feet above varied between 11 and 21 decibels (depending on other noises present in aircraft).

The article gives comparative figures for the Vokes and Burgess silencers. Reference is also made to the exhaust collector ring silencer developed by the Bristol Company.

The Performance of a De Palma Roots-Type Supercharger. (O. W. Schey and H. H. Ellerbrock, Jnr., N.A.C.A. Tech. Note No. 558, March, 1936.) (1105 U.S.A.)

The supercharger has hollow steel impellers running in an alloy casing. The displacement volume is 0.1 cubic foot and experiments were carried out over the speed range 1,000/6,000 r.p.m. The results obtained are in general agreement with those obtained with a N.A.C.A. Roots blower, but show that, on the whole, alloy impellers (such as fitted to the N.A.C.A. compressor) are preferable.

Engine Installation of LZ.129. (F. Sturm, Z.V.D.I., Vol. 80, No. 13, 28th March, 1936, pp. 393-397.) (1123 Germany.)

The 16-cylinder V engine follows closely the OF2 design of the Daimler-Benz firm. This previous design (12-cylinder V) was rated at 750 h.p. and it had been the original intention to boost it to 950 h.p. After considerable amount of experimental work it was decided to increase the number of cylinders rather than add the supercharger. The fuel consumption of the new engine is below 170 gm./b.h.p. hour (.375 lb.) over the power output range—250 to 1,050 h.p. The normal speed range of the engine is 1,300 to 1,450 r.p.m. A 2/1 reduction gear of the Farman type is fitted. Four engines are used, and each has undergone two continuous power runs of 150 hours at full load before being installed.

The engines are reversible, and it is stated that the ship can be brought to rest from 15 m./sec. (32 m.p.h.) in less than 350 m. (400 yards).

Hydraulically-Operated Rotary Air Compressor. (Engineering, Vol. 141, No. 3,665, 10th April, 1936, p. 389.) (1130 Great Britain.)

A star-shaped eccentric rotor is fitted with hinged tips which are thrown outward by centrifugal force. In this way a number of sealed compartments of varying volume are formed. These are partially filled with water, which is thrown outward by centrifugal action and thus acts as a piston, alternately drawing in air and expelling it through the hollow shaft. The water also acts as a lubricant, no oil being required. At the same time the air is cooled. Pressures of the order of 100 lbs./sq. in. are realisable.

Cooling Characteristics of a 2-Row Radial Engine. (O. W. Schey and V. G. Rollin, N.A.C.A. Report No. 550, 1935.) (1276 U.S.A.)

The tests were carried out in the full-scale tunnel on a Pratt and Whitney G.R. engine rated at 700 b.h.p. at 2,500 r.p.m. The engine was installed in a Vought aeroplane, using the standard cowling and baffles.

The tests show that a minimum air speed of 120 m.p.h. was required to ensure satisfactory cooling at full load (1½ lbs./sq. in. boost). Increase of B by 50 per cent. increases the temperature difference between air and cylinder by approximately 16 per cent.

Doubling the air speed reduced the temperature difference by the same amount. The change of temperature difference with power output was the same irrespective of whether the increased power was obtained by increased boost at normal speed or by increasing r.p.m. at normal boost.

The Automatic Synchronisation of Engines. (L'Air, No. 394, 1st April, 1936, p. 12.) (1344 France.)

If in the case of a multi-engine plane the individual power units operate at different speeds, various objectionable phenomena such as cabin noise, vibration of tail unit, etc., are liable to occur.

Synchronisation by revolution counter is generally not accurate enough.

The problem has been solved in America, France and (probably) Germany by the installation of more sensitive devices.

The French scheme depends on the fact that the cage of a differential drive has no tendency to revolve if the two bevels are driven at equal speed (and opposite direction). By suitably interconnecting two engines through such a drive, for example, any difference in speed can be made to act on the throttle of one of them, the other throttle being hand-controlled.

The differential drive will then keep the two engines in step, and by suitable adjustment of the intermediate linkages this arrangement can be rendered stable.

Note by Abstractor.—The differential drive will obviously require long lengths of flexible shafting for coupling to the engines. The twist in these shafts, together with changes in friction of the gear wheels (wear) is thought to render the continuous working of such a device problematical in spite of the favourable impression conveyed by the author of the article.

French Streamline Radiator (Villard-Ferlay). (Flugsport, Vol. 28, No. 9, 29th April, 1936, p. 189.) (1351 Germany.)

The illustrations show the installation of the cooling elements inside a venturi. Internal baffles direct the flow, whilst external flaps control the quantity of air passing.

Heavy Oil Engine Using Constant Atomisation and a Limited Maximum Pressure. (P. Dumanois, Comp. Rend., Vol. 202, No. 17, pp. 1,409-1,411.) (1401 France.)

High explosion pressures in an injection engine are objectionable. They introduce bearing troubles and call for a heavy mechanism. By suitable injection control, constant pressure burning can be achieved which overcomes these difficulties. In the author's opinion the small reduction in thermal efficiency is balanced by improved reliability.

Combined Exhaust Filter and Silencer for Diesel Engines. (Fuel, Vol. 15, No. 6, June, 1936, pp. 164-166.) (1596 Germany.)

The filter replaces the ordinary silencer. It contains a layer of granular material which affects a catalytic combustion of partially burnt exhaust gases and oil mist.

Catalytic action starts at approximately 250°C., and the filter temperature may reach 500°C. in extreme cases.

The apparatus is stated to have passed extensive tests carried out by the Daimler-Benz A.G. (Germany).

Processes of Movement in Gas Columns, with Particular Reference to the Exhaust and Scavenging Processes of Two-Cycle Engines. (A. Pischinger, Forschung, No. 6, Sept.-Oct. and Nov.-Dec., 1935, pp. 245-247 and 273-280.) (1602 Germany.)

A method is described for investigating processes of flow in pipes and containers. A number of examples are given, illustrating the usefulness of the method by comparing the experimental results with those obtained by calculation. The effect of the length of the exhaust pipe is discussed, and the most suitable length is indicated.

Engine Type and Acceptance Tests. Discussion between M. Victor and C. Waseige. (Les Ailes, No. 781, 4th June, 1936, pp. 4-5.) (1611 France.)

At present French engine tests (Norme Air 6105) are carried out in two parts. The so-called " nomologation " or type tests consist of 50 hours bench tests at 9/10 nominal power, after engine characteristics (power and consumption on a speed and throttle basis) have been determined. These tests are followed by the so-called acceptance tests, consisting of 25 hours at half-power, 15 hours at 9/10

power, and 2 hours at nominal power (all bench tests). From the discussion it appears that these acceptance tests are considered of very little value. More information would be obtained from a short run at excess r.p.m. and under condition of boost (engine inclined). Flying tests are also required in which the aeroplane is artificially braked, so as not to exceed climbing speed, although the flight is carried out horizontally near the ground at full throttle. Under such conditions, temperature determination should be carried out both for engine and lubricating oil and any undue engine vibration (criticals) noted.

It is held that a few hours under variable conditions are preferable to long continuous runs under steady load (type tests of 150 hours carried out in some countries).

It appears that an international convention as to engine rating (definition of nominal, maximum and maximum permissible power) is urgently wanted.

A clear indication of the span between maximum and maximum permissible and the time the latter can be kept up would be specially useful.

Engine Trouble in LZ.129. (Aeroplane, Vol. 50, No. 1,307, 10th June, 1936, p. 754.) (1650 Germany.)

According to statement by Electron Metals (Germany), the magnesium pistons supplied by their firm gave entire satisfaction. The trouble was due to damage of one of the connecting rod bolts on the outward journey and its replacement by unsuitable material in South America. This bolt broke on the return trip.

Results of Inadequate Cooling. (Autom. Ind., Vol. 74, No. 22, 30th May, 1936, pp. 770-771.) (1653 U.S.A.)

Lubricant in a cylinder must act both as a pressure seal and also prevent metallic contact of piston rings. If the clearances are too great, the oil film will be blown away by the gas. If the oil film is too thin, the piston rings will scour the liner. Clearances cannot be kept uniform unless care is taken to prevent cylinder distortion. Not only must the cooling be sufficient, but it must also be suitably distributed. Examples of good designs (water-cooled) are illustrated.

Gnome-Rhône 18-Cylinder Engine. (Inter. Avia, No. 326, 25th May, 1936, p. 3.) (1658 France.)

Arising out of experience gained with the 1,000 h.p. 14-cylinder K.14 engine, Messrs. Gnome & Rhône (Paris) have brought out the 18-cylinder L.18, rated at 1,360 h.p. The cylinders are nitrated and the number of cooling ribs increased (pitch 4 to 5 m/m.). A new compressor is used (dural impeller) fitted with a special oil seal.

Diameter of engine, 4.6 feet.
Bore, 146 m/m. Stroke, 180 m/m.
C.R., 5.5. Weight 710 kg.
Estimated performance at 9,000 feet, 1,360 h.p.
Flight tests are not yet available.

The Supply of Petrol to France in Peace and War-Time. (Capt. Murtin, Riv. Aeron., Vol. 11, No. 10, Oct., 1935, pp. 84-91, and Revue du Ministère de l'Air, No. 4, April, 1935, pp. 462-474.) (352 France.)

In France the production of petrol from oil wells is insignificant (less than 3 per cent. of the peace-time requirements). The supply of petrol is thus in the hands of British and American concerns, and in case of war could be cut off

entirely, since the French fleet is not powerful enough to ensure supplies in all cases. Attention is thus concentrated on home-produced fuels. These fall under the following classes:—

1. Benzol—(a) high-temperature distillation.
   (b) low-temperature distillation.
2. Alcohol.
3. Charcoal for gas producers.
4. Hydrogenation.
5. Coal distillates and tar oils (Diesel fuels).

On account of requirements of the explosives industry, (1) and (2) are only available in restricted quantities and thus have to be mixed with imported petrol. In an emergency producer gas from charcoal could be employed for lorries. Hydrogenation and oil fuels present the most important lines of development. The former requires very expensive plants, and the author is of the opinion that only by the development of the Diesel engine, both for motor cars and aeroplanes, can France be rendered independent.

Synthetic Lubricating Oils. (H. Koch, Z.V.D.I., Vol. 80, No. 2, 11th Jan., 1936, pp. 49-51.) (798 Germany.)

The well-known Fischer-Tropsch process for the production of liquid fuels from CO/H_2 mixtures (synthetic petrol) also yields unsaturated mono-olefines. Fractions rich in this product are known in the trade as Kogasin. They polymerise at 100°C. in the presence of suitable catalysists ($Al_2 Cl_6$) to a viscous oil, the yield being approximately 60 per cent. These synthetic oils are stated to be equivalent to Pennsylvanian oil in lubricating quality. Not only do they remain liquid to surprisingly low temperature (approximately 35°C.) but they also resist oxidation and yield very little coke.

The oils have already received application as transformer oils and good results have been obtained in I.C. engines. It is stated that ultimately these oils will replace the natural product, since they can be produced under controlled conditions (chemical composition determined with narrow limits).

German Patent Fuel for Diesel Engines (*U.S. Patent No.* 2,028,308). (Chem. Absts., Vol. 30, No. 5, 10th March, 1936, p. 1,543.) (1040 Germany.)

To a hydrocarbon oil heavier than naphtha an addition is made of about 0.5—20 per cent. of a fluid aliphatic hydrocarbon material containing more than 2C atoms and having more than one multiple C bond, such as diacetylene, to reduce the pressure at which spontaneous combustion of the oil would normally occur.

The patentees are I. G. Farben, A.G.

Classification of Lubricating Oils. (E. Neyman, Chem. Absts., Vol. 30, No. 5, 10th March, 1936, p. 1,548.) (1042 Germany.)

It has been established that for the same class of hydrocarbon oil, the viscosity increases with increase of molecular weight. The author proposes a system of classifying lubricating oils on this basis, the quotient of the molecular weight by the density giving a number which is characteristic of the oil.

Lubricating Oil Mixture (*U.S. Patent No.* 2,018,758). (Chem. Absts., Vol. 30, No. 1, 10th Jan., 1936, p. 282.) (1044 U.S.A.)

About 0.5 per cent. or more of the reaction product of an organic acid such as stearic or oleic acid with an alkylol group of an alkylol-amine such as triethanol-amine is added to a mineral lubricating oil to increase the load-bearing capacity of the oil.

The Influence of Pressure, Concentration and Temperature and the Rate of Slow Oxidation and Liability to Spontaneous Ignition of Pentane Oxygen Mixtures at Temperatures above 300°C. (M. Prettre, Comp. Rend., Vol. 202, No. 11, 16th March, 1936, pp. 954-956.) (1062 France.)

The influence of pressure on the delay period is very marked. Equimolecular mixtures of pentane and oxygen are the most active, which seems to point to the formation of associated molecules (peroxide).

Combustion-Engine Temperature by the Sodium Line-Reversal Method. (M. J. Brevoort, N.A.C.A. Tech. Note No. 559, March, 1936.) (1106 U.S.A.)

Temperatures given by the Na line reversal method are compared with those calculated from the indicator diagram. As the flame appears before there is a measurable pressure rise, agreement over the earlier part of the combustion is hardly to be expected. Beginning at 20° A.T.D.C., the two methods give practically identical gas temperatures. Since the indicator method necessarily gives average temperatures, whilst the Na line gives the flame or highest temperature, this agreement throws some doubt on the accuracy of the measurements.

JS—Diagrams for Air. (S. Awano, Aer. Res. Inst. Tokio, Vol. 11, No. 135, February, 1936.) (1120 Japan.)

The diagrams cover the range 0.1 to 200 kg./cm.^{2} and -80°C. to 2,800°C.

Influence of Magnetic Field on the Coefficient of Viscosity of Liquids. (H. S. Venkataramiah, Phys. Berichte, Vol. 17, No. 5, 1st March, 1936, p. 509.) (1125 Germany.)

A marked effect was produced in the case of p–A2 oxyanisol just below its melting point. The clear molten liquid showed no effect.

Storage of Gasolene Containing Gum—and Colour-Forming Constituents. (H. C. Weber, Chem. Absts., Vol. 30, No. 6, 20th March, 1936, p. 1,992.) (U.S. Patent 2029748.) (1135 U.S.A.)

Nascent hydrogen is generated below the surface of the stored fuel. An atmosphere of hydrogen is maintained over the surface.

Lubricating Oils and Motor Fuels. (Siemens and Halske, Chem. Absts., Vol. 30, No. 6, 20th March, 1936, p. 1,992.) (French Patent 789567.) (1136 Germany.)

Deposition of solids and tars on the walls of engine cylinders is reduced by modifying the surface of the metal (treatment with S, P or Se compounds).

Similar effects may be produced by addition of these substances to the fuel or oil.

The Oil-Film in High-Speed Engines. (H. Brillic, J.S.A.E., Vol. 38, No. 4, April, 1936, p. 36.) (Abstract from Journal de la Société des Ingenieurs de l'Automobile.) (1173 France.)

The lubrication system for journal bearings here proposed is said to reduce the friction for this type of bearing to that of roller bearings. It consists of replacing the customary 360° oil film totally surrounding the bearing by two elementary films opposite one another, each extending over an arc of 60° and separated by two equal central reservoirs. The analytical and experimental study of this system is preceded by a discussion of heat generated in the lubricant and bearings of high-speed engines.

Oxidation Inhibitors for Lubricating Oils (British Patent No. 442161.) (Chem. and Ind., Vol. 55, No. 21, 22nd May, 1936, p. 439.) (1496 Great Britain.)

Mineral lubricating oils are protected against oxidation at >150° (150°–200°) by addition of an aromatic inhibitor (0.1 per cent.) which is stabilised by a directly

linked ether, or thio, seleno-, or telluro-ether group. Preferred examples are hydroxy—or amino-diaryl ethers or sulphides.

Some Effects of Argon and Helium Upon Explosives of Carbon Monoxide and Oxygen. (E. F. Fiock and C. H. Roeder, N.A.C.A. Report No. 553, 1936.) (1561 U.S.A.)

The addition of the inert gas decreases the flame speed, the effect being more marked in the case of Argon. The results are in contradiction with earlier results obtained by Stevens using the same apparatus.

Differences in moisture content of the mixture is offered as a possible explanation.

Vibration Phenomena During the Combustion in an Engine Cylinder. (Labarté, Vichnievsky and Manson, Comp. Rend., Vol. 202, No. 19, 11th May, 1936, pp. 1,566-1,568.) (1507 France.)

Records taken by the cathode ray indicator on a C.F.R. engine show presence of a fundamental vibration of frequency 2,300/sec., together with secondary vibrations of higher frequency. The fundamental frequency is unaffected by piston position or engine speed, but apparently depends on the engine bore. The secondary vibrations vary in frequency during the stroke, having a maximum of approximately 16,000/sec. at T.D.C. and falling to 6,000/sec. at the end of expansion. These vibrations are heavily damped and are probably due to waves along the cylinder axis.

Ignition and Flame Development in the Case of the Injection Engine. (O. Holfelder, Forschungsheft, No. 374, Supplement to Forschung, Vol. 6, No. 5, Sept.-Oct., 1935.) (Translated in N.A.C.A. Tech. Memo. No. 790, March, 1936.) (1576 Germany.)

The experiments were carried out in a cylindrical bomb approximately 4in. diameter and 16in. long attached to the compression space of an air compressor (12.6in. bore, 18.9in. stroke).

Prior to injection, the air is circulated through the bomb and is passed back to the compressor over an electric heater. No outside air is allowed to enter except to make good leakage. After prolonged motoring, the air reaches temperatures of the order of 500°C. at pressures varying between 20 and 30 atmospheres, depending on the amount of throttling in the circuit. To prevent danger of lubricating oil explosions, the compressor is lubricated with colloidal graphite. After isolation of bomb, a Bosch pump produces a single injection of the fuel along the axis of the bomb and the spray is photographed on a rotating film, the illumination being light transmitted through narrow longitudinal windows. By means of a rotating sector the exposure time is limited to 10^{-3} seconds. Twenty-five exposures are taken on a single film, the total time covered being approximately .05 seconds.

By interposing a green filter between the source of light (arc lamp) and the bomb, the subsequent ignition of the fuel jet can be photographed as well as the shadow of the original spray.

The bomb is also fitted with an indicator (piezoelectric) and thermocouples.

Ignition lag (of the order of .006 sec.) could thus be measured either direct from the flame photographs or inferred from the pressure and temperature records.

The smallest and most accurate value is given by the flame photograph (pressure and temperature show increasing lags). On the other hand, the time to complete combustion is given more nearly by the pressure record, since the flame loses its actinic qualities before the reaction has finished.

The following general conclusions are reached:—

1. Combustion generally starts at the edge of the spray.
2. High air temperatures and high oxygen concentration reduce ignition lag.
3. The pintle valve jet produces longer lags than the needle jet.
4. The presence of an impact plate increases lags.
5. Initiation of combustion causes an acceleration of the burning spray. Towards the end of combustion there is a drop in speed below that of the non-burning spray.
6. Conditions in the bomb chamber are remarkably steady (no turbulence) and the motion of the spray is confined to small limits which repeat satisfactorily in successive explosions.
7. The provision of a heated pre-combustion chamber of the Benz type enables the use of heavy fuels which normally possess unsatisfactory characteristics.

Abstractor's Note.—The absence of turbulence is considered a serious defect of the method, even for comparative purposes. An injection lag of .006 sec., as obtained in the bomb, corresponds to over 43° crank angle for an engine running at 1,200 r.p.m.

Relation Between the Pressure Vibrations Accompanying Detonation, Delay of Pressure Rise, Time to Maximum Pressure and Value of Maximum Reached in a Carburettor Engine. (M. Vichnievsky, Comp. Rend., Vol. 202, No. 20, 18th May, 1936, pp. 1,655-1,656.) (1589 France.)

The advent of the cathode ray oscillograph enables the accurate study of the indicator diagram under detonating conditions. The intensity of gas vibrations (audible knock) and the rate of pressure rise (bouncing pin reading) depend on the spark advance and the compression ratio in a manner which differs for different fuels. The relative order of merit of a series of fuels thus depends on the condition of test. In the C.F.R. method, fuels are compared at the C.R. and spark-setting and thus may account for some of the inconsistencies noted.

Report on the Activities of the Reichsanstalt for 1935. *General Experiments to Determine the Lubricating Value of Oils.* (Phys. Zeit., Vol. 37, No. 8, 15th April, 1936, pp. 283-284.) (1590 Germany.)

The experiments described fall under the following heads:—

1. Determination of friction—design of special machine.
2. Surface finish of various bearings and its measurement.
3. Current rectifying property of oil film in various bearings.
4. Absorption of oil on metal surfaces and strength of resultant film.
5. Comparative test on ball and needle bearings—slip is affected by speed, load and viscosity of oil film. (It appears that slip increases with speed and viscosity, but diminishes with load).

Investigation of Explosive Oxidation of Methane. (N. Kobseff and others, Fuel, Vol. 15, No. 6, June, 1936, p. 180.) (1597 U.S.S.R.)

The effects of different factors upon the results obtained in the experimental explosion of methane are carefully examined. These include:—

(1) Pressure.
(2) The percentage of CH_4, O_2, N_2, CO, H_2, and H_2O contained in the original mixture.
(3) The diameter and form of the explosive vessel.

Period of Induction in the Inflammation of Gas Mixtures. (A. E. Malinowsky, Fuel, Vol. 15, No. 6, June, 1936, p. 180.) (1598 U.S.S.R.)

The theoretical calculation is based on the assumption that the rate of charge in the number of active centres depends, in the same way as it does in Semenoff's treatment, on both the first and the second powers of the available concentration.

Photographic Investigation of Flame Movements in Gaseous Explosions—Part VII, Spin in Detonation. (W. A. Bone and others, Fuel, Vol. 15, No. 6, June, 1936, p. 180.) (1599 Great Britain.)

The experimental work deals mainly with detonations under various conditions in a moist $2\,CO + O_2$ mixture.

Detonation in an explosive gaseous medium is the propagation, as a wave, of a condition of intensive combustion, initiated and maintained in a shock wave by radiation from an associated flame front. Under certain conditions, the " head " of detonation begins to rotate in the medium, eventually pursuing a spiral tract along the tube quite close to the walls; the medium does not, however, rotate as a whole.

Nature of the Octane Scale. (E. B. Evans and others, Fuel, Vol. 15, No. 6, June, 1936, pp. 182-183.) (1600 Great Britain.)

The octane-number scale used for characterising the knock rating of fuels for internal-combustion engines is discussed. It is shown that the term " octane-number " has no meaning unless the engine and conditions of determination are rigorously specified. It is not suggested that the octane-heptane scale, which has generally simplified the problem of knock-rating determination, be abandoned, but that it be interpreted in the light of the experimental results which are described in this paper.

Estimation of the Combustion Products from the Cylinder of the Petrol Engine and its Relation to Knock. (A. Egerton and others, Fuel, Vol. 15, No. 6, June, 1936, p. 183.) (1601 Great Britain.)

Analysis of the gases from the cylinder of a Delco knock-rating engine showed that some combustion occurred in the knocking zone prior to the passage of flame. It is suggested that knock is due to the sudden explosion of a pre-sensitised portion of the charge in an engine cylinder owing to a branch chain type of reaction among the substances formed by partial combustion.

The Process of Flow of the Fuel in Carburettors of Internal-Combustion Engines. (H. Petersen, Forschung, Vol. 7, No. 1, Jan.-Feb., 1936, pp. 11-18.) (1603 Germany.)

In order to elucidate the problems connected with the flow of fuel and the atomisation of the fuel jet in a carburettor, tests were made on models, using water. The emission of fuel is determined by the pressure in a dead space which forms in the air-sheltered area of the injector pipe. The pressure and shape of this dead space depend on the geometrical dimensions and positions of the choke and jet. The processes in the mixing chamber were recorded photographically and an expression was obtained for the disintegration of the fuel jet within the mixing chamber.

Determination of Carbon Monoxide in Mixtures with Hydrogen and Methane. (G. Meyer and A. Sloof, Fuel, Vol. 15, No. 6, June, 1936, p. 184.) (1604 Holland.)

The carbon monoxide is converted into carbon dioxide by iodine pentoxide at a temperature of 120 to 130°C. Under these conditions the methane does not react. The CO_2 is determined volumetrically in an apparatus which is described and illustrated in this paper. Differences between the values found and those calculated for the percentage of carbon monoxide are within reasonable limits.

Lubricating Oil. (W. F. Jacques, Chem. Absts., Vol. 30, 20th May, 1936, p. 3,631.) (Swiss Patent 177,588.) (1608 Switzerland.)

Upper cylinder lubricant for internal combustion engines, for mixture with the fuel, consists of 300-350 parts of castor oil, 5-10 parts of colloidal graphite,

300-315 parts of $C_6 H_6$, 300-330 parts of light petrol, and 35-40 parts of a solution of camphor and naphthalene in $C_6 H_6$ and acetone.

Hydrocarbons. (I. G. Farbenind, Chem. Absts., Vol. 30, No. 10, 20th May, 1936, p. 3,631.) (German Patent 600,722.) (1608A Germany.)

Hydrocarbons, especially lubricating oils, are improved by addition of a solution of highly polymerised oxygenated vinyl compounds, such as the polymerised vinyl ester of stearic acid.

Anti-Knock Agent for Liquid Fuels. (Y. Veda, Chem. Absts., Vol. 30, No. 10, 20th May, 1936, p. 3,622.) (Japanese Patent 113,623.) (1609 Japan.)

Addition of 1 to 5 per cent. of a benzene or acetone solution of nitro-compounds of aniline (such as tetra-nitro-methylaniline or hexanitrodiphenylamine) and terpenes (such as pinine, terpineol or camphor) to gasolene or to light or heavy oil increases the power of fuel and prevents knocking. Addition of a urea deriv. improves the agent.

Comparative Studies of Slow Combustion of Methane, Methyl Alcohol, Formaldehyde and Formic Acid. (W. A. Bone and J. B. Gardner, Proc. Roy. Soc., Vol. 154, No. 882, 1st April, 1936, pp. 297-328.) (1628 Great Britain.)

The hydroxylation theory affords the most probable explanation of the analytical facts now established by researches on the slow oxidations of methane, ethane, ethylene, benzene, toluene, etc., over a wide range of pressure. (In this connection the work of Newitt and his collaborators in their pressure-oxidations is of outstanding significance). The theory also satisfies kinetic and other requirements. Although diligently sought for throughout these experiments, no sign of any initial " peroxidation " of the methane molecule was ever detected.

The Initial Formation of Alcohols During the Slow Combustion of Methane and Ethane at Atmospheric Pressure. (D. M. Hewitt and J. B. Gardner, Proc. Roy. Soc., Vol. 154, No. 882, 1st April, 1936, pp. 329-335.) (1629 Great Britain.)

The experiments show that during the slow combustion of methane and ethane at atmospheric pressure, the formation of methyl and ethyl alcohols precedes that of the corresponding aldehydes.

Catalysis and Inhibition of a Homogeneous Gas Reaction. The Influence of Nitric Oxide and the Decomposition of Diethyl Ether. (L. A. K. Stavely and C. N. Hinshelwood, Proc. Roy. Soc., Vol. 154, No. 882, 1st April, 1936, pp. 335-348.) (1630 Great Britain.)

The decomposition of diethyl ether is catalysed by nitric oxide in large amounts. The catalysis resembles that caused by iodine in that the activation energy is much lower than that of the normal reaction. Some of the nitric oxide is removed in simultaneous oxidation reactions.

Small quantities of nitric oxide, on the other hand, exert a striking inhibiting effect on the normal decomposition.

The Influence of Pressure on the Spontaneous Ignition of Inflammable Gas-Air Mixtures. IV—Methane-Ethane and Propane-Air Mixtures. (D. T. A. Townend and E. A. C. Chamberlain, Proc. Roy. Soc., Vol. 154, No. 881, 2nd March, 1936, pp. 95-112.) (1636 Great Britain.)

The view previously put forward that ignition in the lower system occurs when temperature and pressure condition favour the survival and further oxidation of aldehydes has found further support. " Knock " in internal-combustion engines most probably arises in circumstances responsible for pronounced chemical

reactivity in the unburnt explosive medium (*cf.* Egerton, Llewellyn Smith, and Ubbelohde, " Phil. Trans." A, Vol. 234, p. 443, 1935). The experiments have indicated without exception that the circumstances of compression ratio, working temperature, and engine speed responsible for the phenomenon, correspond with the pressure and temperature conditions requisite for spontaneous ignition within an appropriate time-lag, whatever the chemical mechanism involved.

Engine Knock and the Action of Anti-Knock. (J. Lorentzen, Fuel, Vol. 15, No. 6, June, 1936, pp. 166-173.) (Translated from Z. f. Angew Chemie., 1931, p. 130.) (1651 Germany.)

Experiments were carried out in a cylindrical bomb using pentane and hexane as fuel. From the pressure records it is concluded that knock or detonation is the rapid completion of combustion of partially-burnt products through which the flame has already once passed. This completion is generally brought about by a pressure wave set up when the flame hits the wall of the container. These views correspond with those of Maxwell and Wheeler (Ind. & Eng. Chem., 1928, Vol. 20, p. 1041) based on flame photographs. The presence of anti-knock (lead tetra-ethyl or iron carbonyl) mixed with the liquid fuel did not prevent detonation. The decomposition products of freshly-burnt dope blown into the bomb, however, proved effective.

It is clear that the decomposition is brought about automatically in the engine during the compression stroke. In the bomb, the low temperature of the mixture prior to ignition (30°C.) delays decomposition of the dope till after the explosion and thus prevents its effect.

Fuel Vapour Lock. (Autom. Ind., Vol. 74, No. 22, 30th May, 1936, pp. 773-774.) (1652 U.S.A.)

At the last A.S.E. summer meeting, Messrs. Barber & Kuleson presented a vapour lock chart by means of which it is possible to specify fuel system temperatures. The volatility characteristics of the fuel are specified in terms of Reid vapour pressure and initial range of the A.S.T.M. distillation.

Conversely, if the vapour lock characteristics of the fuel system are known, the required fuel can be specified. In this way, waste by unnecessary venting of vapour before the metering jet of the carburettor can be avoided. In some cases the loss amounted to as much as 15 per cent. of the total fuel supplied.

Engine Types and Fuel Requirements. (Autom. Ind., Vol. 74, No. 22, 30th May, 1936, pp. 774-775 and 780.) (1655 U.S.A.)

Heating the inlet charge of a normal carburettor engine in order to improve atomisation results in a drop in power. The need for heating can be avoided by:—

(a) Injecting the fuel into a supercharger where it is atomised mechanically.
(b) Timed injection in the induction pipe (close up to the inlet valve).
(c) Injection into the cylinder during the compression stroke.

(a) holds considerable promise provided recondensation in the diffusor passages is guarded against. A simple method is to use a flat venturi type of expansion chamber with a groove and sharp edge on the inclined surface on which the fuel collects. On reaching the edge the fuel flies off in a fine mist.

(b) presents considerable difficulty to maintain constant mixture ratio. Extra turbulence has to be provided in the cylinder (shrouded inlet valve).

(c) Owing to short time available for mixing, only weak mixture can be burnt. This is to some extent offset by the possibility of using high compression ratios.

A heat accumulator in the form of a hot shell is required to obtain consistent ignition, and even then it is difficult to prevent fuel condensation on the plug at light load.

Influence of Fuel-Oil Temperature on the Combustion in a Pre-chamber Compression-Ignition Engine. (H. C. Gerrish and B. E. Ayer, N.A.C.A. Tech. Note No. 565, April, 1936.) (1470 U.S.A.)

The results showed that heating the fuel oil to 750°F. increased the injection period, changed the rate of injection, and eliminated the spray core. Engine tests showed that the ignition lag, rate of pressure rise, and maximum cylinder pressure were reduced. The indicated mean effective pressure, the fuel economy, and the thermal efficiency were slightly increased. Operation of the engine when the fuel was heated to 750°F. was smoother, the exhaust clearer, and the carbon formation in the combustion chamber considerably less than when the fuel was heated to 124°F.

Cathode Ray Indicator and Combustion Research. (Autom. Ind., Vol. 74, No. 22, 30th May, 1936, pp. 768-770.) (1656 U.S.A.)

The audible sound obtained during detonation is due to the ring of the metal cylinder when struck internally by the steep pressure rise. Internal pressure waves in the gas are of much lower frequency.

The widely-accepted theory that Diesel knock depends primarily on the amount of fuel injected before ignition takes place is doubted. Thus wide variation in fuel injection distribution per degree of crank angle brought about by heating the fuel before injection has only little effect on knock The high rate of pressure rise observed for fuel with long ignition lags are held to be due to the formation of a more homogeneous mixture on account of the longer time during which turbulence acts.

Interesting results were obtained with a fuel injection pump. The fuel pump injects 1/5 of fuel; the remainder is injected after ignition. Poor fuels could be dealt with in this manner. It is suggested that similar results could be obtained by a single pump using a double step cam.

Fuel Level Indicators (Floatless). (Flugsport, Vol. 28, No. 5, 4th March, 1936, pp. 101-102.) (955 Germany.)

A wire loop carrying an electric current is immersed in the tank. The temperature of the wire outside the liquid differs from the rest on account of the difference in rate of heat dissipation.

If a pure metal is used, this difference of temperature causes appreciable differences in electric resistance compared with a dry reference wire.

New Echo Sounding Apparatus. (French Patent No. 787,383.) (A. Askenasy, Revue de l'Armée de l'Air, No. 80, March, 1936, pp. 349-355.) (993 Holland.)

The sender emits a continuous note which is modulated by the echo. The frequency of the modulation depends on the time of the echo, *i.e.*, the height.

Electrical circuits are used both for emission and reception of the sound, an " anti-fading " device ensuring constant intensity of modulation irrespective of intensity of echo. This device also gives some indication of the nature of the reflecting surface (soil).

Although primarily designed for audible sounds, supersonic waves or even ultra short wireless waves are envisaged.

In this connection the author refers to French Patents Nos. 787,451 and 748,642. The latter has been reviewed in L'Aeronautique, Nos. 169 and 170, 1933, by P. Leglise.

A Piezo-Electric Chronograph. (E. P. Tarvil, Comp. Rend., Vol. 202, 1936, No. 12, pp. 1,016-1,017.) (1099 France.)

The quartz crystal is maintained under resonant electric vibrations whilst a polarised beam of light is sent through it in a suitable direction.

The vibrations produce changes in the plane of polarisation which in their turn cause the emergent beam to become periodically extinguished after passage through an analyser.

This periodicity is recorded on a rotating film using an arc lamp; the author has measured time intervals of the order of 1/100,000 sec. (displacement on film ½ m/m.).

Fuel Indicators. King Seeley Telegauge. (Autom. Ind., Vol. 74, No. 13, 28th March, 1936, Advert. p. 47.) (1118 U.S.A.)

Electric current heats up a bimetal " sender " placed in a sealed chamber above the tank. The heating up causes the strip to bend away from the electric contact and then break the circuit till the strip cools when the process repeats. As the float in the tank rises, the strip is bent mechanically so that a greater heating current is required to break the circuit.

The receiver carried on the dashboard consists of a second bimetal strip operating a pointer. On account of electrical lag, the readings are not affected by fluid splash.

The Breakdown of Venturi Air Meters at High Speeds. (G. Kiel, L.F.F., Vol. 13, No. 3, 20th March, 1936, pp. 88-91.) (1188 Germany.)

The calibration breaks down when the air speed reaches the velocity of sound at the narrowest section.

Double venturis naturally reach this condition sooner than orthodox types. Used on aircraft, increasing height favours instability for both types.

Rain-Gauge Recorder for Small Showers. (E. Marz, Z. Instrum., Vol. 56, No. 4, April, 1936, pp. 167-173.) (1299 Germany.)

The electrical resistance of a filter paper is affected by the shower and this variation recorded by suitable amplifiers.

Aircraft Compass Characteristics. (J. B. Peterson and C. W. Smith, N.A.C.A. Report No. 551, 1936.) (1333 U.S.A.)

A description of the test methods used at the National Bureau of Standards for determining the characteristics of aircraft compasses is given. The methods described are particularly applicable to compasses in which mineral oil is used as the damping liquid. Data on the viscosity and density of certain mineral oils used in United States Navy aircraft compasses are presented. Characteristics of navy aircraft compasses IV to IX and some other compasses are shown for the range of temperatures experienced in flight.

Results of flight tests are presented. These results indicate that the characteristic most desired in a steering compass is a short period, and in a checking compass a low overswing.

The Development of a Mechanically-Operated Frequency Meter and Tensiometer—Part II. (W. E. Stitz, A.C.I.C., Vol. 8, No. 701, 1st Sept., 1935.) (1334 U.S.A.)

The Report describes a new and improved frequency meter as well as new methods of using the instrument for determining the fundamental frequencies of vibration of aircraft structures, as well as of engine mounts and propellers.

Horizontal and Vertical Guidance of Aircraft by Wireless (in Case of No Visibility). (French Patent No. 787250, M. H. Chïreïx, Revue de l'Armée de l'Air No. 82, May, 1936, pp. 589-594.) (1676 France.)

The object of the invention is first to guide the aircraft horizontally for the last few kilometres towards the aerodrome, and finally cause it to descend along a predetermined path till contact with the ground is made.

For this purpose two wireless beams of wave-length 7 and 8 m. respectively are directed along the required line of approach. Both beams possess identical low frequency modulation and are 90 degrees out of phase.

The aircraft possesses two receiving circuits tuned to 7 and 8 m. respectively and of identical amplification. These circuits are connected to two mutually perpendicular voltage plates of a cathode ray oscillograph.

Correct line of approach is characterised by the spot of the oscillograph describing a circle (out of line produces an ellipse).

Vertical guidance for landing makes use of paths of equal field intensity, which for short waves of the types considered are parabolic with the vortex close to the emitter and the ground tangential.

When following such a path, the circle on the oscillograph screen will maintain a constant diameter.

Analysis of the Three Lowest Bending Frequencies of a Rotating Propeller. (F. Liebers, N.A.C.A. Tech. Mem. No. 783, January, 1936.) (Translated from L.F.F., Vol. 12, No. 5, 31st August, 1935.) (1035 Germany.)

The available literature on rotating propeller oscillations reveals a lack of uniformity in interpretation, particularly as concerns the data on the overtone frequency with respect to the centrifugal forces.

The present report is a survey of the existing data for computing the bending frequency and a check on the dependability of the calculating methods.

Torsion and Buckling of Open Sections. (H. Wagner and W. Pretschner, N.A.C.A. Tech. Memo. No. 784, January, 1936.) (Translated from L.F.F., Vol. 6, 5th December, 1934.) (1036 Germany.)

Following an abstract of the well-known theory of torsion in compression, the writers give directions for practical calculations.

Experiments in support of the theory of torsion of plain and flanged angle sections are described. The existing minor discrepancies are explained through the subsequent modification of the theory (allowance for elastic deflections).

Fatigue Strengths of Be-Ni. and Be-Contracid under Torsion. (W. Meissner, Phys. Berichte, Vol. 17, No. 5, 1st March, 1936, p. 506.) (1122 Germany.)

The specimen wires vibrated approximately 20 days (2×10^6) times at the rate of 37 vibrations/sec. The beryllium alloys compared favourably with Cr-Mo-Va steel.

The Distribution of Vertical Stress in Beams. (Schnadel, Phys. Berichte, Vol. 17, No. 5, 1st March, 1936, p. 519.) (1128 Germany.)

In addition to bending and shearing stresses, short beams are subjected to radiating vertical stresses by the direct action of the load. These may produce important buckling effects.

Cylinder Wear. (S. W. Sparrow and T. A. Scherger, J.S.A.E., Vol. 38, No. 4, April, 1936, pp. 117-125.) (1157 U.S.A.)

Engine cylinder wear is always associated with ring and piston wear. The relative importance of the three factors is a question of design and materials. Alterations may benefit one and deleteriously affect the other factors. Moreover, minimum wear does not necessarily mean longest time between overhauls.

On account of the smaller bearing surface, ring wear is generally much greater than cylinder wear (diametral wear .01in. and .001in. respectively on 3in. bore after 10,000 miles).

Piston wear is erratic since distortion is liable to produce variable area of contact.

Speaking generally, cylinder wear shows a pronounced maximum near the top of the stroke. This is probably associated with lack of lubricant and predominance of abrasives (products of combustion and contamination of induction air).

Abrasives introduced artificially give accelerated wear curves of the same type as obtained normally.

Of the rings, the scraper usually wears least, but relative ring wear depends enormously on piston clearance and oil metered to the individual cylinders. This quantity depends on bearing fits and distance of bearing from oil pump entry (effective pressure drop). Moreover, the temperature of individual cylinders may vary appreciably, even in water-cooled engines.

The problem of wear is thus complicated, but inadequate lubrication, *i.e.*, inefficient distribution of the oil, is held to be the main cause.

Possible effects due to corrosion are not considered to be of importance by the authors.

A Comparison of Corrosion-Resistant Steel (18% Chromium–8% Nickel) and Aluminium Alloy (24 ST—American Specification). (J. E. Sullivan, N.A.C.A. Tech. Note No. 560, March, 1936.) (1169 U.S.A.)

All things considered, and in the absence of more extensive data on load-carrying capacities of stainless-steel structure, it is believed that aluminium alloy at present offers the best combination of properties for fabricated structures of stiffened sheet and for columns. For highly-stressed fittings carrying lugs, good design and psychological consideration point toward the use of steel forgings, heat-treated subsequent to forging.

Material for Exhaust Valves of Aero Engines. (E. Schmidt and H. Mann, L.F.F., Vol. 13, No. 3, 20th March, 1936, pp. 71-84.) (1186 Germany.)

Austenitic alloy steels of the following average composition are recommended for high duty engines:—

C	...	...	.32%
Mn	...	...	1.27%
Si	...	...	1.11%
Ni	...	...	31.10%
Cr	...	...	12.25%
Tu	...	...	3.72%
Fe	...	...	Rest

The valves have to be sodium-cooled to keep the working temperature below 800°C. The stems require surface hardening (nitriding or rolling) and attention has to be paid to suitable materials for the stem guide.

Thirty references.

Determination by Analysis and Experiment of Deformations and Stresses in Square Plates with Supported Edges, Uniform Load and Great Deflections. (R. Kaiser, Z.A.M.M., Vol. 16, No. 2, April, 1936, pp. 73-98.) (1295 Germany.)

The deformations and stresses are computed by the method of finite differences and found in good accordance with measurements made by the author. Great deflections produce besides the flexural stresses, just as in a vault, a stress uniform throughout the thickness of the plate, which causes the maximum stress to be shifted from the centre of the plate to a zone at a certain distance. Therefore the maximal stress is smaller than it would result by the theory of small deflections.

(Available as Translation No. 326.)

Vibrations of Elastic Ropes. (R. Höger, Z.A.M.M., Vol. 16, No. 2, April, 1936, pp. 109-116.) (1297 Germany.)

The author calculates the vibrations of an elastic rope suspended from two points of equal height. The position of equilibrium being assumed to be an arc

of a circle, the differential equations for the small vibrations are deduced by Hamilton's principle. As a numerical example, the first four characteristic vibrations are computed and figures drawn.

Remarks on the Elastic Axis of Shell Wings. (P. Kuhn, N.A.C.A. Tech. Note No. 562, April, 1936.) (1332 U.S.A.)

The definitions of flexural centre, torsional centre, elastic centre and elastic axis are discussed. The calculation of elastic centres is dealt with in principle and a suggestion is made for the design of shear webs.

The Damping Power of Crankshaft Steels. (A. Appendrodt, Z.V.D.I., Vol. 80, No. 17, 25th April, 1936, pp. 517-518.) (1339 Germany.)

The damping was measured on a Foppl-Pertz vibration machine, readings being taken for the material as received and after 50,000, 200,000, 1.25×10^6, 6.25×10^6 and 31.25×10^6 reversals.

The damping capacity varies largely with the composition of the steel. Least damping was shown by a tempered Cr-Ni-T steel, highest damping by Siemens Martin St 42-11. The damping alters with number of reversals, but usually settles down to a steady value after 6×10^6 reversals, provided no previous fracture takes place.

Lining of Bearings with Lead Bronze in a Rotating Magnetic Field. (Eng. Tutchkevitch and Rutes, U.S.S.R., Aeron. Eng., No. 4, 1936.) (1319 U.S.S.R.)

The increase in power of aero engines makes higher demands on all details of the engine. One of the most serious and difficult problems in the construction of aero engines is that of obtaining very high quality bearings.

The linings of bearings which are at present of lead bronze are not yet perfect in quality. Various methods have been used for lining bearings. The anti-friction laboratory of the V.I.A.M.* tried the centrifugal method, which has certain advantages for the casting of cylindrical bodies, and a series of other methods of lining, before the technological process of stationary lining with employment of spray cooling was evolved.†

Conclusion.—1. The use of a rotating magnetic field for lining annular and cylindrical casts gives a greater fineness of structure with the resultant improvement of the mechanical quality and of compactness of the cast.

2. In many cases lining in a rotating magnetic field can replace centrifugal casting.

3. When lining with lead bronze it was found to be more convenient to use a specially designed armature " stator " creating a magnetic field, inside the preparation, instead of the stator of a motor. This gives a better centring, more profitable use of the magnetic flow, and completely eliminates the possibility of " screening " of the steel lining.

4. The employment in the technological process of lining in a rotating magnetic field improves the mechanical qualities, reduces the porousness of lead bronze, and gives an even distribution of lead in the bronze.

5. It is essential to continue experiments with a rotating magnetic field, having established the connection between the improvement of certain of the qualities of lead bronze and anti-frictional properties.

Propeller Crankshaft Vibration Problems. (H. H. Couch, Mechanical Engineering, Vol. 58, No. 4, April, 1936, pp. 215-221.) (1430 U.S.A.)

Propeller vibrations are usually initiated by torsional vibrations of the crankshaft. Service tests have shown that trouble usually ensues, in the case of radial

* All-union Institute of Aviation materials.
† " Aeronautical Engineering," No. 36, 1935.

engines, if the twist of the rear end of the crankshaft is more than $\frac{1}{2}°$. The author describes a magnetic type of pick-up which enables propeller vibrations due to bending to be recorded under operating conditions (on the ground). A complete study requires about 50 oscillograph pictures, samples of which are reproduced. Torsional blade vibrations are of much higher frequency than those due to bending. Resonant periods cannot always be avoided by design of engine, nor can propellers be made by large enough section to be safe without undue weight increase. It has, moreover, been found that this latter remedy simply shifts the trouble from the propeller back to the engine. Smooth driving torque (distribution) together with a damper is the best general solution.

References: Air Corps Information Circulars, Nos. 683 and 684.
Trans. A.S.M.E., Vol. 52, 1930, pp. 139-152.

Properties of Aluminium Sheet. (S. Horiguchi, Aer. Res. Inst. Tokio, No. 138, April, 1936.) (1584 Japan.)

A study has been made of the effect of cold-working and annealing on the properties of aluminium sheet. It is concluded that in order to get best results the reduction in thickness should be limited to 50 per cent. and the final annealing carried out at 350°C.

The Effect of Changes in a Torsionally Vibration System on the Natural Frequencies of the System. (W. A. Tuplin, Phil. Mag., Vol. 21, No. 144, June, 1936, pp. 1,097-1112.) (1610 Great Britain.)

In engine installation, the normal procedure is to design the plant and calculate the vibration characteristics afterwards. If troublesome criticals are found within the running range, an attempt is then made to alter the frequency by adjustment of the inertia or torsional stiffeners. The effect of such alteration is easily seen, if the adjustment is applied equally to every member of the system (*i.e.*, either inertia or stiffeners multiplied by the same factor q throughout. In the former case the frequency changes as $\sqrt{q}$, in the latter as q).

If, however, the various elements are altered in a different degree, the resultant effect is not so apparent and will require a recalculation of the vibration characteristics.

The author shows how, in the case of small changes in stiffeners and inertia, this complete recalculation can be saved and the effect on frequency estimated from the shape of the original elastic curve.

A New Attack Upon the Problem of Fatigue of Metals, Using X-Ray Methods of Precision. (H. J. Gough and W. A. Wood, Proc. Roy. Soc., Vol. 154, No. 883, 1st May, 1936, pp. 510-539.) (1624 Great Britain.)

Three conditions of crystals have been observed—the perfect grain, the dislocated grain and the crystallite. The first gives rise, on the X-ray photograph, to a single sharp spot, and in the authors' experiments (normalised mild steel) has a size of the order of 10^{-2} cm. Dislocated grain and crystallite are stages under stress—first loosening and then breaking up into small parts (10^{-4} to 10^{-5} cm.) with indiscriminate orientation. Perfect grains are maintained under stresses up to the limit of proportionality. As the yield point is approached, a small proportion of dislocate grain and crystallites began to appear. At complete yield the material consists entirely of dislocated grain with a small proportion (by volume) of crystallites. From fatigue tests the authors conclude that cycles of safe stress range are unable to cause progressive damage to the state of the structure. This remains stable with increasing stress range, the proportion of crystallite gradually increasing. The ultimate fatigue failure is associated with a definite condition of structure precisely similar to that existing under static failure. It is probable that this correspondence will hold for all forms of loading, but this conclusion requires further tests.

Physical Properties of Surfaces. III—The Surface Temperature of Sliding Metals. The Temperature of Lubricated Surfaces. (F. P. Bowden and K. E. W. Ridler, Proc. Roy. Soc., Vol. 154, No. 883, 1st May, 1936, pp. 640-656.) (1625 Great Britain.)

A method is described for measuring the surface temperature of sliding metals. The temperature reached depends upon the load, speed, coefficient of friction, and thermal conductivity of the metals, and is in good agreement with theory. With readily fusible metals the surface temperature reached corresponds to the melting point of the metal. With less fusible metals the local surface temperature may exceed 1,000°C.

Even with lubricated surfaces the temperature (under boundary lubrication conditions) is high and may exceed 600°C. This high surface temperature will cause a local volatilisation and decomposition of the lubricant, and is a cause of the breakdown of the boundary film.

The Equilibrium and Elastic Stability of a Thin Twisted Strip. (A. E. Green, Proc. Roy. Soc., Vol. 154, No. 882, 1st April, 1936, pp. 430-455.) (1632 Great Britain.)

A theoretical investigation is made into the elastic stability of a thin twisted strip, and it is found that the strip does become unstable at a definite value of the twist, which is slightly greater than that observed experimentally. This difference is probably due to lack of straightness in the strip. For steel the instability occurs when the couple reaches 1.43 the times the St. Venant couple. This result is independent of the ratio thickness : width.

Two different strips of steel have been used in the experiments. The results are represented on separate graphs for each strip, and also in a non-dimensional form on one graph.

Castigliano's Principle of Minimum Strain Energy. (R. V. Southwell, Proc. Roy. Soc., Vol. 154, No. 881, 2nd March, 1936, pp. 4-21.) (1634 Great Britain.)

If

U = total elastic strain energy of system,
U_0 = strain energy resulting from the imposition of specified displacements,
U_1 = additional energy caused by the imposition of specified forces,
$U = U_0 + U_1$ . . . (1) (provided Hooke's law is obeyed).

Castigliano's theorem states that :—

" The stress distribution resulting from given forces applied to a body initially in a state of ease can be deduced from the condition of equilibrium combined with the conditions for a minimum value of U." This follows at once from (1)—for if U_1 is given, U has its least value of $U_0 = 0$.

The author uses this principle to investigate condition of compatibility of strain which hitherto has been obtained by purely kinematical reasoning. Similarly, some problems first treated by St. Venant are treated in a more direct manner (uniform flexure of flat ring).

The method can be applied to all problems of equilibrium, reducing them in fact to problems in the calculus of variations.

Applications of X-Rays to Industrial Problems. (J. R. Townsend and L. E. Abbott, Bell Tele. Pubs., B-918, February, 1936.) (1642 U.S.A.)

Within the well-defined limits of usefulness set forth in this paper, we have in X-ray examination of engineering structures a useful non-destructive test of quality. Gamma rays may be used in certain applications to reveal hidden defects where these defects might not be readily revealed by X-rays.

Barometric Pressure and Resistance to Cold. (J. Giaja and S. Gelineo, Comp. Rend., Vol. 202, No. 19, 11th May, 1936, pp. 1,613-1,614.) (1508 France.)

From experiments on rats (rate of oxygen consumption) it is concluded that a reduction in barometric pressure very markedly reduces the resistance to cold.

The Variation of the Coefficient of Surface Resistance. (C. S. Durst, J. Met. Soc., Vol. 62, No. 264, April, 1936, pp. 290-291.) (1585 Great Britain.)

In a previous paper the author gave physical reasons for supposing that the coefficient of surface resistance varied with the vertical temperature gradient of the air near the surface; values since obtained for the resistance coefficient by Sutcliffe are claimed to support this theory.

The Temperature and Constituents of the Upper Atmosphere. (D. F. Martyn and O. O. Pulley, Proc. Roy. Soc., Vol. 154, No. 882, 1st April, 1936, pp. 455-486.) (1633 Great Britain.)

Radio measurements of the heights and electron densities of the ionised regions are found to show considerable cooling of the upper atmosphere during the night. The absolute temperature between the E and F regions of the ionosphere are found, from consideration of the electron collision frequencies, to reach values of the order of 1,000°K. Such high temperatures exist both in summer and winter daytime. From the observed rate of cooling at night it is found that considerable water vapour is present in the ionosphere, an average concentration being 1 part in 6,000 volume. The high temperatures found are attributed mainly to the absorption of solar ultra-violet energy by ozone, in concentration of 1 part in 104. Consideration is given to the temperatures below 100 km. A maximum temperature is found at 60 km. and a minimum of 160°K. at 82 km. Noctilucent clouds are found to give an air pressure of 10^{-3} mm. at a height of 105 km., in good agreement with the electron collision frequency measured at height.

The air densities found by Lindemann and Dobson at a height of 105 km. are slightly greater than those deduced in this article from radio observations. Making allowance for an approximation in Lindemann's results, however, agreement is obtained.

The Production of High Rotational Speeds. (J. W. Beams and E. G. Pickels, Z. Instrum., Vol. 56, No. 3, March, 1936, pp. 124-126.) (974 Germany.)

The original device of Henriot and Huguenard (air-borne gyroscope) was improved by modifications of the rotor design. Sketches show the new arrangement which makes speed up to 2,500 revolutions/second possible.

Physics and Reality. (A. Einstein, J. Frank. Inst., Vol. 221, No. 3, March, 1936, pp. 349-382.) (1003 U.S.A.)

" In my opinion the quantum theory does not seem likely to produce a usable foundation for physics. On the other hand the field (relativity) theory is unable to give an explanation of the molecular structure of matter and of quantum phenomena."

Cone Propeller Lifeboat, "Royal Silver Jubilee." (Engineering, Vol. 141, No. 3,666, 17th April, 1936, p. 438.) (1163 Great Britain.)

The impeller revolves in a conical casing plåced amidships and cut away on the underside to form both an inlet and outlet for the water. The axis of rotation is perpendicular to the longitudinal axis of the boat and to the direction of water discharge.

On the Directional Properties of Airscrew Sound. (J. Obata and others, Aer. Res. Inst. Tokio, Vol. 11, No. 134, pp. 1-6.) (972 Japan.)

Model airscrews ($\frac{1}{3}$ or $\frac{1}{4}$ actual size) were rotated by means of an electric motor on an isolated stand, and the spacial distributions of the sound intensity were

determined with a sound measuring arrangement consisting of a condenser microphone, an amplifier, a suitable electrical filter, and a thermal milliammeter. Polar diagrams are given for three two-bladed and two four-bladed airscrew models of different blade sections. The results agree in the main with those published quite recently by E. Z. Stowell and A. F. Deming. It is concluded that the directional property differs somewhat with the shape of the blade as well as with the number of blades.

Apparatus for the Magnetic Recording and Reproduction of Sound Waves. (Z.V.D.I., Vol. 80, No. 9, 29th February, 1936, pp. 267-268.) (989 Germany.)

Earlier apparatus of this type employed a steel wire running in a controlled magnetic field. In this new form a film is coated with a thin layer of powdered iron. The film speed is 1 m./sec., and spools for thirty minutes' reception weigh about 2½lbs. Small thickness of the film leads to a corresponding reduction in air gap which reacts favourably on the fidelity of reproduction.

Heat Measurement of Hot Water Installation by Thermopyle Recorder. (A. Egal and R. Chevalier, Comp. Rend., Vol. 202, No. 11, 16th March, 1936, pp. 930-933.) (1063 France.)

The cold and hot water junction of a thermopyle consisting of 200 couples register the return and outlet temperature of the water respectively. The thermo couples actuate an electric meter of the usual magnetic type, the connection being maintained over a definite interval of time (a few seconds only).

The number of such contacts made is governed by the rate of water flow (vane recorder).

The Acoustic Diffraction Grating and its Application to Sound Analysis. (E. Thienhaus, Phys. Zeit., Vol. 37, No. 5, 1st March, 1936, p. 184.) (1114 Germany.)

The analysis of noise by means of methods employing electric filters becomes very difficult if the noise varies rapidly.

The author describes a new method in which the sound to be analysed is superposed on a supersonic beam of frequency 50,000/sec. impinging on a concave grating. The resultant spectrum is analysed by means of a small condenser microphone.

Porous Sound Absorbers of Variable Flow Resistance. (L. Cremer, Phys. Berichte, Vol. 17, No. 5, 1st March, 1936, p. 517.) (1127 Germany.)

Homogeneous packing and packing in layers of gradually increasing rigidity is compared.

An initial layer of cotton wool is very efficient in damping out high frequency sounds.

The Photo-electric Measurement of the Diurnal and Seasonal Variations in Daylight and a Globe Integrating Photometer. (W. R. Atkins and H. H. Pool, Phil. Trans. Roy. Soc., Series A, Vol. 235, No. 752, 30th April, 1936, pp. 245-272.) (1620 Great Britain.)

During 1930 the daily maxima ranged from 6.9 to 197.6 kilolux and the illumination intervals between 20.7 and 1323. The illumination at sunset on clear days averages .65 kilolux at sea or on the coast. The monthly percentage of the annual illumination integral in kilolux hours ranges from 1.25 (December) to 16 in July.

The Direct Positive or Reversal Process in Photography. (H. Baines, Chem. and Ind., Vol. 55, No. 23, 5th June, 1936, pp. 450-454.) (1644 Great Britain.)

Although the negative/positive process must continue to be almost universally used, there are cases where a direct procedure is becoming of interest. Such cases arise in colour photography, amateur cinematography and certain kinds of inexpensive self-portraiture (automatic). In the original form, these direct processes required very exact exposure times, which rendered their use difficult for the amateur. Recent improvement in development technique has, however, given much greater latitude, although the range of the standard positive/negative process cannot yet be approached.

Transatlantic Long-Wave Radio Telephone Transmission and Related Phenomena from 1923 to 1933. (A. Bailey and H. M. Thomson, Bell Tele. Pubs., B. 887, October, 1935.) (986 U.S.A.)

It is shown that transatlantic long-wave radio field strength is related to the 11-year cycles of terrestrial magnetic activity, sunspots, solar limb-prominences, and ultra-violet radiation. The directness of correlation between long-wave radio and these other phenomena is apparently only approximate. Very good seasonal and monthly correlation is obtained between magnetic activity and daylight radio transmission. Magnetic storms are shown to have prolonged and delayed effects on day and night radio transmissions, obscuring tendencies of 27-day recurrences in long waves.

Accumulators for Aeroplanes. (Airc. Eng., Vol. 8, No. 85, March, 1936, pp. 81-82.) (1031 Great Britain.)

This accumulator is intended for civil aircraft and is not fitted with an unspillable device as required for military machines. The following special features are claimed:—(1) Patented " topping up " device to prevent overfilling and spillage of electrolyte. (2) Means of " topping up " with distilled water without disturbing accumulator or removing cover. Voltage 12. Capacity 26 amp. hours at 20-hour rate of discharge. Weight 34 lbs. (including acid).

A New Static Electricity Motor. (P. Joliver, Comp. Rend., Vol. 202, 1936, No. 12, pp. 1,030-1,032.) (1102 France.)

The motor consumes 2 watts (45×10^{-6} amp. at 45×10^{-3} volts) and has a useful output of .52 watt at 3,000 r.p.m.

Investigations on the Preliminary Stages of Spark Formation in Various Gases by the Use of the Wilson Chamber. (U. Nakaya and F. Yamasaki, Proc. Roy. Soc., Vol. 153, No. 880, 1st February, 1936, pp. 542-544.) (1627 Great Britain.)

Previous experiments on the application of the Wilson chamber to the study of spark discharge were continued with improved equipment both in electrical and mechanical designs. With the present apparatus the authors succeeded in taking reproducible photographs of the cloud tracks of preliminary discharge of spark in non-homogeneous fields. Discharge clouds were obtained in air, nitrogen, oxygen, carbon dioxide, hydrogen, and nitric oxide, and it was found that the form and structure of the preliminary discharge were quite different for different gases. The effect of admixture of a small quantity of some organic vapour was studied. Some chain compounds containing chlorine or iodine, such as chloroform, methyl iodide, etc., were very effective in transforming the positive branched streamers in air into a smooth track.

Hyper-Frequency Wave Guides—General Considerations. (G. C. Southworth, Bell Tele. Pubs., B. 927, April, 1936.) (1643 U.S.A.)

A peculiar form of electrical propagation is described. It makes use of extremely high frequencies—even beyond those generally employed in radio. In some respects it resembles ordinary wire transmission, but unlike the latter there are no return conductors—at least of the usual kind.

In this transmission, electromagnetic waves are sent through guides made up either of an insulator alone or of an insulator surrounded by a conductor. In a special case this insulator may be air. Some of the fundamental pieces of apparatus used in experimental work are described. They include generators, receivers and wave-meters.

The Radiaura. (Aeroplane, Vol. 50, No. 1307, 10th June, 1936, p. 743.) (1646 Great Britain.)

Using a wave-length of 5 metres, a novel system of double modulation makes possible multiplex conversation between any number of transmitters within a predetermined range. Visual warning can be provided of the entrance of one or any number of aeroplanes within a danger zone of predetermined extent and depth around any given machine. Small transmitters placed on obstacles would give a pilot distance bearing and elevation of these obstacles.

REVIEWS.

Combustion Chamber Design for Oil Engines.

By Paul Belyavin. Published by Constable. Price 3/6.

This book is concerned solely with the design of combustion heads for engines of the compression ignition type and contains a number of line drawings of these heads with the author's comments. The information given is as much as one can reasonably expect in a book of small size and low cost, but it is not enough to enable a reader to appreciate the advance that has been made and the direction in which further advance is possible.

In fact, the book falls between two stools. The non-technical reader who is sufficiently interested in mechanical matters to wish to know what the interior of his engine looks like is best catered for by a series of carefully drawn and shaded pictures, while the reader who really wants to know all about his engine and why it has been designed in a particular way will find the book disappointing.

Possibly due to price and size limitations, certain important types of combustion chambers, such as that used on Junkers aero engines and also the Ricardo type with rotational swivel are omitted altogether, and the few formulæ which are introduced are so loosely written that they are difficult to interpret. Whether the formula given on page 29 is of any importance is doubtful, but there is no excuse whatever for not putting it in proper mathematical form.

The fact is that the author has set himself an impossible task in attempting to deal with this subject adequately in a book of this size.

Elements of Practical Aerodynamics.

By Prof. Bradley Jones, M.S. Published by Chapman and Hall, Ltd. Price 18/6.

Professor Bradley Jones is Professor of Aeronautics in the University of Cincinnati and he states in the preface that his experience in teaching has convinced him that a book intended for the class-room must differ from a book intended for a practical engineer. This book, which is of the class-room variety, deals with all the usual aerodynamical subjects in a manner which is intended to be as simple as possible, in fact, with two exceptions, the author has succeeded in avoiding the use of calculus throughout the work.

It is difficult to see that the book will be of much interest for teaching in this country, as the use of American symbols and, in certain cases, the American language make it unsuitable, but it is of interest to enquire why in certain modern technical works it should be deemed necessary to avoid calculus.

It is difficult to understand why authors put themselves to the trouble of devising ingenious but cumbrous proofs of certain theorems in algebra when the calculus proof is so much simpler, where the only apparent result is to encourage their pupils to indulge in a form of intellectual laziness, for a neglect or refusal to learn calculus can be described in no other way. Among certain students the mere name of calculus invokes a sort of stage fright, as if it were a subject only to be understood by those with superhuman brains. But it would seem to be the duty of professors to combat such ideas and to see that their students understand something about a subject which, in its more elementary forms, is less difficult than long division.

In any case it is impossible, at any rate in this country, for any student to study aerodynamics seriously without a grounding in calculus, and it is difficult to avoid a feeling of surprise that this should be seriously contemplated in America.

INTERAVIA, A.B.C.

Published by the Société Anonyme d'Editions Aéronautiques Internationales. Price 12/6.

This book consists mainly of a list of addresses of aeronautical firms, societies and organisations in every country in the world. It is written in five languages, English, French, German, Italian and Spanish, all headings, prefaces, etc., being repeated in each language. There is also a dictionary of the usual aeronautical terms which is arranged in such a manner that translation is easy.

There is no question whatever that a reference book on these lines is an extremely useful publication, but it stands or falls on the accuracy of its contents and the convenience or rapidity with which a reference can be looked up. As far as it has been possible to check the information, it is certainly accurate, though there are a few spelling mistakes in the British section. The book is very conveniently arranged for reference, there being a complete index to every item with the name of the country and the number of the page required.

The book is a most useful work of reference.

SMALL TWO-STROKE AERO ENGINES.

By C. F. Caunter. Published by Sir Isaac Pitman and Sons, Ltd. Price 6/-.

Mr. Caunter has collected together particulars of small two-stroke aero engines from the various countries which have produced such engines, and this book contains such information together with photographs of the various types. Details of fuel consumption, weights, and other useful information is included.

In spite of the extreme simplicity of the two-stroke engine, which can be reduced to only three moving parts, piston, connecting rod and crankshaft, this type of motor has always been the Cinderella among internal combustion engines. The fact is that simplicity does not compensate for its disadvantages, its penchant for losing unburnt mixture through its exhaust port and the difficulty of inducing gas flow into the cylinder at high speed.

These difficulties arise largely from the use of the piston as an inlet and exhaust valve, in addition to its normal function, but once this arrangement is abandoned in favour of a more satisfactory form of valve gear complications arise which destroy the chief advantage of the two-stroke over the four-stroke type of engine. The use of this type of motor has consequently been restricted to small sizes where specific fuel consumption is unimportant and where its simplicity and cheapness are advantageous.

The renewed interest in low-powered aircraft has provided a new field for the two-stroke motor and a number are being developed for this purpose. They vary in the number of cylinders used, the arrangements of these cylinders and in the valving arrangements, but it is noticeable that the most successful types are those which adhere most closely to the original simple design. Improvements have been made in the positioning of the ports, in lubrication systems, compression ratios, etc., and the fuel consumption has been brought down to 0.56lbs. per h.p. per hour in the case of the Scott A.25, which seems to be the best figure so far attained.

Although it seems unlikely that the two-stroke motor will take the place of the powerful four-stroke types used for large civil and military aircraft, they should possess definite advantages for low powers in their cheapness and simplicity, and the study that Mr. Caunter has made of this subject is to be welcomed.

Those interested in light aircraft will find much in the book that is of interest, and the book should assist the designers and manufacturers of these engines by providing knowledge of what their rivals are doing.

INTERNATIONAL ORGANISATION IN EUROPEAN AIR TRANSPORT.
By Laurance C. Tombs. Published by Columbia University Press and by Mr. Milford in England. Price 15/-.

The author of this book is a member of the Communications and Transit Section of the League of Nations Secretariat and the book contains a history of the negotiations and agreements between European nations on the subject of air transport. It is not exactly light reading, but it contains much that is of interest to aeronautical history, and is a useful and important addition to any aeronautical library.

As far as it concerns this country the great difficulties met with by British negotiators in clearing the course for Empire airways are clearly set out; the difficulties with Turkey, who still declines to permit international air lines to cross her Asiatic territory; the refusal of Italy to allow Imperial Airways to enter Italy from France, so that the journey between Basel and Genoa had to be made by train. Even when this difficulty had been overcome further difficulties arose with France, and the air route had still to be interrupted with a train journey, and this continued until the year 1935.

It is probable that in the future that the improved performance of aircraft will permit of an Empire Air Service which will call only at stations under the British flag, so that air communications will be free from these way-leave difficulties.

It is to be hoped that this book will, as it deserves, be read by air transport operators in America. An appreciation of our difficulties would indicate how much easier it is to establish long distance air lines in the New World, and would explain why air transport has reached a higher state of development in America than in Europe.

PRACTICAL AIRCRAFT STRESS ANALYSIS.
By D. R. Adams, A.F.R.Ae.S. Published by Sir Isaac Pitman and Sons, Ltd. Price 8/6.

Mr. Adams is lecturer in Stress Analysis and Design at the De Havilland Aeronautical Technical School and the book is intended for use by students and draughtsmen. The reader is assumed to have such knowledge of stress matters as can be obtained by studying a standard work on the mechanics of materials and is shown how to apply this to aircraft stressing.

In many cases the standard formula is repeated for the convenience of the reader, and there are many worked out examples and diagrams; an intelligent student who studied the book carefully should have no difficulty in stressing ordinary components.

A book of this type is useful for educative purposes provided that the student is thoroughly conversant with the groundwork of the subject. The danger consists in the fact that a reader may simply take a formula from the book and apply it without understanding its derivation. This method of automatic stressing saves thought, and succeeds if the component to be stressed is similar to an example in the book, but if there is not such an example the reader is lost. There is also a risk that the student may not appreciate the importance of certain small deviations from the standard.

The dangers can be avoided by proper groundwork, and although the author states that the student is " advised " to amplify the text by reference to standard works, this advice does not go far enough. No student should be allowed to use the book until he is familiar with a good standard text book on the subject. To such students the work will be useful, teaching them how to apply their acquired knowledge to the special subject of aircraft stressing and acting as an aide-mémoire to the precise form of formulæ, the derivation of which they already know. To place the book in the hands of someone without these qualifications is to place a premium on mental laziness.

Within these limitations the book is useful as the letterpress is clear and it is well illustrated with diagrams. The tables included are appropriate, but there is something wrong with the last four lines of Table 1.4, there being nothing to show what are the exact materials referred to.

AIRPORT MANAGEMENT.

By Major L. F. Richards. Published by Sir Isaac Pitman and Sons, Ltd. Price 5/-.

Major Richards, who was Chief Aerodrome Officer at Croydon Aerodrome for some ten years, has written a useful and informative book. He starts by giving a large number of precepts gathered from his experience in which there is obviously much wisdom, and concludes with appendices containing the official regulations concerning airports and aircraft.

Apparently the pilots who annoy him most are private owners with too much money and too few manners. These are said to take a pleasure in ignoring regulations and inventing excuses for so doing. But there cannot be many of them and Major Richards points out that regulations exist which can be invoked against such people, and that for certain offences a penalty of six months' imprisonment can be inflicted. It would seem, therefore, that the airport manager can hit back with effect whenever he wishes to do so. The only people who invariably get their own way are the "Customs," who are said to have such decided and unalterable views as to their requirements that it is not the slightest use to argue with them.

Major Richards' book should be read by all those interested. It is well and entertainingly written, and he has apt remarks to make on all features of aerodrome work. The appendices are a useful addition to the work, but, like all Air Ministry regulations, are liable to amendments at short notice.

MANUAL OF METEOROLOGY. VOL. II. COMPARATIVE METEOROLOGY.

2nd Edition. By Sir Napier Shaw. Published by the Cambridge University Press. Price 36/-.

The first edition of this book was published eight years ago and increased information on the subject has made it necessary to publish a new edition with certain revisions. Although it has not been possible to revise the book entirely from the point of view of the year 1935 yet errors and omissions have been corrected and new figures have, in certain cases, been substituted for those previously given. Several matters have also been added to the supplement.

This work is the standard text-book on the subject with which it deals and no student of the atmosphere can afford to be without it.

PROCEEDINGS.

TWENTY-FOURTH WILBUR WRIGHT MEMORIAL LECTURE.

The Twenty-fourth Wilbur Wright Memorial Lecture, entitled "Surface Films and Lubrication," by D. R. Pye, Esq., M.A., Sc.D., M.I.Mech.E., F.R.Ae.S., was delivered before the Society on Thursday, May 21st, 1936, at 9.15 p.m., in the Aeronautical Section of the Science Museum, South Kensington, before a distinguished company of members and guests.

The chair was taken by Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P., President of the Society. The function was held at the Science Museum by kind permission of the Director, Lieut.-Colonel E. E. Mackintosh, D.S.O.

The lecture was preceded by the annual Council Dinner at which the following were present:—

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P. (President).
Captain P. D. Acland.
His Excellency the American Ambassador (R. W. Bingham, Esq.).
Major B. F. S. Baden-Powell, Hon. F.R.Ae.S., F.R.A.S., F.R.Met.Soc.
Major T. M. Barlow, M.Sc., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S. (Vice-President).
His Excellency the Belgian Ambassador (the Baron E. de Cartier de Marchienne).
Prince Otto von Bismarck (German Counsellor).
Sir William Bragg, F.R.S. (President of the Royal Society).
Griffith Brewer, Esq., Hon. F.R.Ae.S.
Major G. P. Bulman, O.B.E., B.Sc., F.R.Ae.S.
H. Roxbee Cox, Esq., Ph.D., D.I.C., B.Sc., F.R.Ae.S.
M. J. B. Davy, Esq., A.F.R.Ae.S.
C. R. Fairey, Esq., M.B.E., F.R.Ae.S. (Past-President).
A. H. R. Fedden, Esq., M.B.E., M.I.A.E., M.S.A.E., F.R.Ae.S.
Air Vice-Marshal W. R. Freeman, C.B., D.S.O., M.C. (Air Member for Research and Development).
A. Gouge, Esq., B.Sc., F.R.Ae.S.
Professor F. T. Hill, F.R.Ae.S., M.I.Ae.E.
Professor G. T. R. Hill, M.C., M.Sc., F.R.Ae.S.
J. E. Hodgson, Esq., Hon. F.R.Ae.S.
Major D. H. Kennedy, O.B.E., F.R.Ae.S.
J. M. Kennedy, Esq., O.B.E. (President, Institution of Electrical Engineers).
Captain A. G. Lamplugh, F.R.Ae.S., M.I.Ae.E., F.R.G.S.
Dr. F. W. Lanchester, Hon. F.R.Ae.S., F.R.S., M.Inst.C.E., M.I.Aut.E.
W. O. Manning, Esq., F.R.Ae.S.
Major R. H. Mayo, O.B.E., M.A., A.M.Inst.C.E., F.R.Ae.S.
R. J. Mitchell, Esq., C.B.E., Assoc.M.Inst.C.E., F.R.Ae.S.
Dr. N. A. V. Piercy, F.R.Ae.S.
Professor A. J. Sutton Pippard, M.B.E., D.Sc., M.Inst.C.E., F.R.Ae.S.
Captain J. Laurence Pritchard, Hon. F.R.Ae.S. (Secretary, Royal Aeronautical Society).

D. R. Pye, Esq., M.A., Sc.D., M.I.Mech.E., F.R.Ae.S.
Lieutenant-Colonel M. F. Scanlon (American Assistant Military Attaché for Air).
The Lord Sempill, A.F.C., F.R.Ae.S.
Lieut.-Colonel Sir Francis Shelmerdine, C.I.E., O.B.E., F.R.Ae.S. (Director-General of Civil Aviation).
O. E. Simmonds, Esq., M.A., F.R.Ae.S., M.I.Ae.E., M.P.
Lieut.-Commander L. C. Stevens, U.S.N. (American Assistant Naval Attaché for Aviation).
The Rt. Hon. the Viscount Swinton, G.B.E., M.C. (Secretary of State for Air).
H. T. Tizard, Esq., C.B., A.F.C., F.R.S., F.R.Ae.S. (Chairman, Aeronautical Research Committee).
C. C. Walker, Esq., Assoc.M.Inst.C.E., F.R.Ae.S.
H. E. Wimperis, Esq., C.B., C.B.E., M.A., M.I.E.E., F.R.Ae.S. (Director of Scientific Research and President-Elect of the Society).
Lawrence A. Wingfield, Esq., M.C., D.F.C., A.R.Ae.S.I.

Immediately following the reading of the lecture the Society held a Reception in the Science Museum, at which members of the Society, their friends and many distinguished guests were present. During the evening, by kind permission of the Air Council, the band of H.M. Royal Air Force, conducted by Flight Lieutenant R. P. O'Donnell, M.V.O., played selections. The following is a list of those who attended the Reception and the lecture, in addition to the Council and their guests:—

Major G. H. Abell, O.B.E., A.M.I.Aut.E., A.F.R.Ae.S.; Mrs. G. H. Abell; Vyvyan Adams, Esq., M.P.; Mrs. Adams; N. K. Adams, Esq.; Capitaine de Corvette Albertas (French Air Attaché); Madame Albertas; Wing Commander D. L. Allen, A.F.C., A.R.Ae.S.I.; R. P. Alston, Esq., B.A., A.F.R.Ae.S.; Mrs. R. P. Alston; E. J. Andrews, Esq.; Captain Natal Arnaud (Brazilian Naval Attaché); Madame Natal Arnaud.

Captain F. S. Barnwell, B.Sc., O.B.E., A.F.C., F.R.Ae.S.; C. M. Barter, Esq., B.Sc., A.F.R.Ae.S.; Mrs. C. M. Barter; Miss Bartlett; Miss F. Barwood; E. L. Bass, Esq., A.F.R.Ae.S.; Mrs. E. L. Bass; H. Bateman, Esq., A.C.G.I., B.Sc., D.I.C., A.F.R.Ae.S.; Mrs. Bateman; Her Grace the Duchess of Bedford, D.B.E.; F. A. C. Behenna, Esq.; J. Beilby, Esq.; Flight Lieut. J. C. Belford; Monsieur H. C. Berg (Norwegian Counsellor); Madame Berg; G. D. Boerlage, Esq.; E. C. Bowyer, Esq.; Mrs. E. C. Bowyer; Miss F. B. Bradfield, M.A., A.F.R.Ae.S.; J. H. C. de Brey, Esq.; Group Captain E. F. Briggs, D.S.O., O.B.E., F.R.Ae.S.; Miss Peggy Browne; Group Captain A. B. Burdett, D.S.O. (Secretary, Royal Air Force Club); Aubrey Burke, Esq.; Mrs. Aubrey Burke; Mrs. G. P. Bulman; Dr. F. P. Bowden; Mrs. Bowden; C. Griffith Brewer, Esq., M.A., A.F.R.Ae.S.

Colonel A. Calderara (Italian Air Attaché); J. D. Campbell, Esq., B.Sc., A.R.T.C., A.F.R.Ae.S.; Mrs. J. D. Campbell; Miss C. C. Campbell; R. S. Capon, Esq., O.B.E., M.A., F.R.Ae.S.; Mrs. Capon; Flight Lieut. D. W. F. Bonham Carter; Mrs. Bonham Carter; F. Carse, Esq.; Dr. T. W. Chalmers (*The Engineer*); Air Commodore J. A. Chamier, C.B., C.M.G., D.S.O., O.B.E., A.F.R.Ae.S. (Secretary-General Air League of the British Empire); Mrs. J. A. Chamier; R. H. Chaplin, Esq., B.Sc., A.F.R.Ae.S.; Miss L. Chitty, F.R.Ae.S.; G. S. Laird Clowes, Esq.; Mrs. G. S. Laird Clowes; Sir Alan Cobham, K.B.E., A.F.C., Hon. F.R.Ae.S.; Lady Cobham; the Hon. Sir Hal Colebatch, C.M.G. (Agent-General for Western Australia); Lady Colebatch; J. V. Connolly, Esq., B.E., A.F.R.Ae.S.; Charles Cooper, Esq. (*Engineering*); Miss G. Cottrell; Air Vice-Marshal C. L. Courtney, C.B., C.B.E., D.S.O. (Deputy Chief of the Air Staff and Director of Operations and Intelligence); William Courtenay, Esq., A.R.Ae.S.I. (*Evening Standard*); Mrs. W. Courtenay; Mrs. D. M. Roxbee Cox;

F. F. Crocombe, Esq., A.C.G.I., D.I.C., B.Sc., A.F.R.Ae.S.; W. B. de Ste. Croix, Esq.; Mrs. de Ste. Croix.

R. R. Dalwick, Esq.; W. Davidson, Esq.; S. D. Davies, Esq., B.Sc., A.F.R.Ae.S.; W. C. Devereux, Esq., A.F.R.Ae.S.; Mrs. W. C. Devereux; G. P. Douglas, Esq., M.C., D.Sc., A.F.R.Ae.S.

H. W. Ely, Esq., J.P. (Acting Agent-General for Tasmania); J. L. Emery, Esq., A.F.R.Ae.S.; E. C. Gordon England, Esq., F.R.Ae.S.; Mrs. Gordon England; Miss D. Gordon England.

A. Fage, Esq., A.R.C.Sc., F.R.Ae.S.; Mrs. Fage; V. M. Falkner, Esq., A.F.R.Ae.S.; Mrs. V. M. Falkner; W. S. Farren, Esq., M.B.E., M.A., F.R.Ae.S., M.I.Ae.E.; Mrs. W. S. Farren; Miss A. Farrington; Miss F. Farrington; A. J. Fedden, Esq.; Mrs. A. J. Fedden; Lieut.-Colonel L. F. R. Fell, D.S.O., O.B.E., M.I.Mech.E., F.R.Ae.S.; Mrs. L. F. R. Fell; C. Brian Field, Esq., A.R.Ae.S.I.; Mrs. E. Field; C. R. Field, Esq.; F. A. Foord, Esq., A.F.R.Ae.S.; E. A. Forder, Esq.; Captain A. G. Forsyth; Mrs. Forsyth; Professor A. Fowler, F.R.S. (President, Institute of Physics); Mrs. Fowler; Captain R. Fujita (Japanese Naval Attaché).

Engineer G. Gervassy (Soviet Union Assistant Air Attaché); Colonel Carlos A. Gilardi (Air Attaché, Peruvian Legation); H. R. Gillman, Esq., A.F.R.Ae.S. (Secretary, Society of British Aircraft Constructors); Mrs. H. R. Gillman; Dr. J. Glasspoole (Honorary Secretary, Royal Meteorological Society); J. B. D. Green, Esq.; C. G. Grey, Esq. (Editor, *The Aeroplane*); Mrs. C. G. Grey; P. T. Griffith, Esq., A.F.R.Ae.S.; Commander H. Grondahl (Finnish Naval Attaché, Acting); P. Guilonard, Esq.

Major F. B. Halford, F.R.Ae.S.; A. H. Hall, Esq., C.B.E., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.; Mrs. Hall; E. D. Hall, Esq., A.R.Ae.S.I.; Miss G. Hancock; M. C. Harley, Esq.; Miss N. Harvey; Courtney Haydon, Esq.; Mrs. Courtney Haydon; Air Commodore J. G. Hearson, C.B., C.B.E., D.S.O.; R. C. B. Hendy, Esq., A.M.I.Ae.E.; H. G. Herrington, Esq.; Mrs. H. G. Herrington; Professor A. V. Hill, M.A., Sc.D., O.B.E., F.R.S.,; Mrs. A. V. Hill, Mrs. G. T. R. Hill; Flight Lieut. L. Massey Hilton, D.F.C., A.F.C., A.R.Ae.S.I.; W. F. Hilton, Esq., A.R.C.S., B.Sc., D.I.C.; C. D. Holland, Esq., A.M.I.Ae.E.; Mrs. C. D. Holland; A. J. Hughes, Esq., O.B.E., A.F.R.Ae.S.; Group Captain G. B. Hynes, D.S.O.; Mrs. Hynes.

G. R. Irvine, Esq., A.M.I.Ae.E.; Miss Irvine; H. B. Irving, Esq., B.Sc., F.R.Ae.S.

A. N. Jackson, Esq., B.Sc., A.F.R.Ae.S.; Thurstan James, Esq. (*The Aeroplane*); Mrs. Thurstan James; J. P. Jeffcock, Esq.; Mrs. Jeffcock; W. G. Jennings, Esq., B.Sc., A.F.R.Ae.S.; Mrs. W. G. Jennings; L. W. Johnson, Esq., M.C., M.I.A.E., A.F.R.Ae.S.; Mrs. Johnson; Mrs. P. F. Johnson; E. T. Jones, Esq.; J. L. B. Jones, Esq., B.Sc.

A. S. Keep, Esq., M.C., M.Sc., A.F.R.Ae.S.; Mrs. D. H. Kennedy; Miss A. Kennedy; Miss Kennedy; F. A. King, Esq.; F. R. B. King, Esq.; R. J. Knights-Whittome, Esq., A.R.Ae.S.I.; Mrs. R. J. Knights-Whittome.

M. Langley, Esq., M.I.Ae.E., A.M.I.N.A.; Mrs. M. Langley; W. Lappin, Esq.; C. W. Lawson, Esq., M.Sc.; H. Leaderman, Esq., B.A., B.Sc.(Eng.); Lieut.-Colonel R. E. Lee (Air Attaché, U.S. Embassy); Mrs. Lee; Dr. J. H. Lees; Miss N. C. Lightfoot; Miss Cybil Littleworth; Captain A. G. Ljungdahl (Swedish Air and Military Attaché); C. N. H. Lock, Esq., M.A., F.R.Ae.S.; Mrs. Lock; J. M. Longley, Esq.; V. A. Lowinger, Esq. (Agent for Malaya); Lieut.-Colonel J. A. dos Santos Lucas (Portuguese Representative); G. Lyon, Esq., M.Sc., A.F.R.Ae.S.

W. A. McAdam, Esq. (Agent-General for British Columbia); Mrs. W. A. McAdam; G. McAlpine, Esq., M.I.E.E., A.F.R.Ae.S.; Mrs. V. E. McAlpine,

C. F. G. McCann, Esq. (Agent-General and Trade Commissioner for South Australia); Mrs. McCann; W. A. McKenzie, Esq. (Allied Newspapers); Sir Francis K. McClean, A.F.C., F.R.Ae.S.; Lady McClean; Mrs. I. McClure; R. McWilliam, Esq.; Major Nuridin Mahmoud (Iraqi Military Attaché); J. A. C. Manson, Esq., B.Sc., A.F.R.Ae.S.; Mrs. Manson; Miss Lina Marsh; G. C. Maxwell, Esq., M.C., D.F.C., A.F.C.; Mrs. R. H. Mayo; Count Roman Michalowski (First Secretary, Polish Legation); Miss Middleton; H. H. Morris, Esq.; Mrs. H. H. Morris; Brig.-General Magnus Mowat, C.B.E., M.Inst.C.E., M.I.Mech.E. (Secretary, Institution of Mechanical Engineers).

J. L. Nayler, Esq., M.A., F.R.Ae.S.; Mrs. Nayler; P. P. Nazir, Esq., A.F.R.Ae.S.; Miss M. Newton; Mrs. Niblett.

A. E. Oakham, Esq.; Commander D. Ogg; Mrs. D. Ogg; H.R.H. Prince Alvaro de Orleans Borbon; J. A. Oriel, Esq.; Mrs. J. A. Oriel; R. Orme-Smith, Esq; Mrs. R. Orme-Smith; E. Ower, Esq., B.Sc., A.C.G.I., F.R.Ae.S.; Mrs. E. Ower.

W. M. Page, Esq., C.B.E., M.A. (Educational Adviser to the Air Ministry); Mrs. W. M. Page; M. H. Paranjpye, Esq.; Miss J. R. Parkes; H. E. Perrin, Esq. (Secretary, Royal Aero Club); Mrs. Perrin; Hugh Perry, Esq.; Captain H. Petre, D.S.O., M.C. (President, London Gliding Club); Major C. E. S. Phillips, O.B.E., F.R.S.E. (Secretary, Royal Institution); Mrs. Phillips; Mrs. N. A. V. Piercy; Mrs. Sutton Pippard; A. Plesman, Esq.; Captain L. F. Plugge, F.R.Ae.S., M.P.; Mrs. Plugge; B. Porter, Esq.; Squadron Leader C. H. Potts, A.F.R.Ae.S.; R. W. Potts, Esq., A.R.Ae.S.I.; C. M. Poulsen, Esq. (*Flight*); R. A. Powell, Esq., A.F.R.Ae.S.; Mrs. Powell; Flight Lieut. R. C. Preston, A.F.C., A.M.I.Ae.E.; Mrs. R. C. Preston; Group Captain W. H. Primrose, A.R.Ae.S.I.; H. C. Pritchard, Esq., B.A., A.F.R.Ae.S.; Mrs. J. Laurence Pritchard; Miss L. M. Pulleine; Corps Commander Putna (Soviet Union Air and Military Attaché); Mrs. D. R. Pye; Miss E. M. Pye.

Dr. E. Goodwin Rawlinson; Mrs. Rawlinson; E. F. Relf, Esq., F.R.S., F.R.Ae.S., A.R.C.Sc.; Mrs. Relf; L. G. S. Reynolds, Esq., O.B.E.; Mrs. Reynolds; T. B. Ringwood, Esq., A.M.I.Ae.E.; Mrs. Ringwood; B. G. Robbins, Esq. (Secretary, Institution of Automobile Engineers); E. B. Robinson, Esq., A.F.R.Ae.S.; J. H. Robertson, Esq.; A. P. Rowe, Esq., A.F.R.Ae.S.; Mrs. A. P. Rowe; A. Ryan, Esq., M.Sc., F.I.R.I., A.F.R.Ae.S.

Harold Sadler, Esq.; Flying Officer K. D. Salmon; Mrs. K. D. Salmon; Major J. C. Savage, M.B.E., M.I.Ae.E.; Mrs. J. C. Savage; J. B. S. Savage, Esq.; W. P. Savage, Esq., A.M.I.Aut.E., F.R.Ae.S.; Mrs. M. F. Scanlon; S. Scott-Hall, Esq., A.C.G.I., M.Sc., D.I.C., A.F.R.Ae.S.; M. Shehab-El-Din, Esq.; Lady Francis Shelmerdine; B. S. Shenstone, Esq., A.F.R.Ae.S.; Mrs. S. F. Shenstone; Major B. W. Shilson, O.B.E., M.I.Mech.E., M.I.A.E., F.R.Ae.S.; H. O. Short, Esq., F.R.Ae.S.; Mrs. H. O. Short; F. R. Simms, Esq., M.I.M.E., M.I.A.E., M.I.E.E., M.I.Ae.E.; Mrs. Simms; H. G. Small, Esq.; Professor R. V. Southwell, M.A., F.R.S., M.I.Mech.E., F.R.Ae.S.; D. W. Sproule, Esq., B.Sc.; H. B. Squire, Esq., A.F.R.Ae.S.; Flight Lieut. C. S. Staniland, A.R.Ae.S.I.; Mrs. Staniland; A. V. Stephens, Esq., A.F.R.Ae.S.; J. Stephenson, Esq.; Mrs. L. C. Stevens; H. J. Stieger, Esq., D.I.C., A.F.R.Ae.S.; Mrs. Stieger; W. A. Stone, Esq.; H. Sutton, Esq., M.Sc., F.R.Ae.S.

Nigel Tangye, Esq., A.R.Ae.S.I.; F. J. Tarris, Esq.; Mrs. Tarris; the Acting Agent-General for Tasmania; F. M. Thomas, Esq., A.F.R.Ae.S.; F. O. Thornton, Esq., A.F.R.Ae.S.; O. Thornycroft, Esq., O.B.E., M.B.A., A.F.R.Ae.S.; Mrs. O. Thornycroft; Miss K. M. Thornycroft; Miss Priscilla Thornycroft; Dr. H. C. H. Townend, F.R.Ae.S.; M. R. D. Trewby, Esq., A.R.Ae.S.I.; Mrs. Trewby; J. C. Trotter, Esq.; Major C. C. Turner,

A.F.R.Ae.S. (*Daily Telegraph*); T. H. Turner, Esq., M.Sc., A.R.Ae.S.I.; W. L. Tweedie, Esq., A.F.R.Ae.S.; Mrs. Tweedie.

W. D. Van Os, Esq.; Sir Alliott Verdon-Roe, Kt., O.B.E., F.R.Ae.S., M.I.Ae.E.; Air Commodore R. H. Verney, O.B.E., A.F.R.Ae.S.; C. H. Vidal, Esq.; C. Amherst Villiers, Esq.; Major O. G. C. Villiers, D.S.O.; G. R. Volkert, Esq., F.R.Ae.S.; Mrs. Volkert; Miss B. Voyce.

P. B. Walker, Esq., M.A., Ph.D., A.F.R.Ae.S.; B. N. Wallis, Esq., B.Sc., A.M.Inst.C.E.; Mrs. Wallis; Dr. C. Wallis; Captain C. E. Ward, A.R.Ae.S.I.; Mrs. C. E. Ward; L. P. Walter, Esq.; Mrs. L. P. Walter; Dr. H. C. Watts, M.B.E., M.Inst.C.E., F.R.Ae.S.; Mrs. Watts; Colonel R. Wenninger (German Air Attaché); Mrs. Wenninger; J. E. White, Esq.; E. Weiser, Esq., B.Sc., D.I.C., A.F.R.Ae.S.; D. H. Williams, Esq., B.Sc., A.F.R.Ae.S.; H. A. Wills, Esq., B.E., A.F.R.Ae.S.; Colonel L. M. Wilson, C.M.G., D.S.O., A.R.Ae.S.I.; Mrs. H. E. Wimperis; Mrs. Lawrence A. Wingfield; R. H. Woodall, Esq., A.M.I.E.E., A.M.I.Ae.E.; Commander E. W. R. Woodruff; Major L. F. E. Wouters, M.C. (Belgian Air Attaché); Madame Wouters; Mrs. Horace Wyndham.

R. Zdanowich, Esq., M.A.(Eng.), A.F.R.Ae.S.; Mrs. Zdanowich.

The PRESIDENT (Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P.): The Wilbur Wright Memorial Lecture affords an occasion for members of the Royal Aeronautical Society and many distinguished people to gather together to pay honour to the lecturer of the evening and to the memory of the man, who in co-operation with his brother, Mr. Orville Wright, made the first power-driven controlled flight which has led to such a great change in the thought of the world.

On behalf of the Society I sent Mr. Orville Wright the following cable:—

> "On Thursday next Mr. Pye will deliver the Twenty-fourth Wilbur Wright Memorial Lecture on 'Slippery Surfaces (Lubrication)' before the Royal Aeronautical Society. His Excellency the American Ambassador, His Majesty's Secretary of State for Air, and many other distinguished guests will be present to pay honour and tribute to the pioneering work of your distinguished brother and yourself, appreciation of which is growing as each year passes, bringing with it an ever-increasing importance to what has now become the chief aeronautical lecture of the year. On this the seventieth anniversary of the founding of the Society we all wish you many years of continued happiness and prosperity.
>
> MOORE-BRABAZON, *President.*"

And I received the following reply:—

> "Greetings to the members and guests assembled for the Wilbur Wright Lecture on this Seventieth Anniversary of the founding of the Society. These have been seventy years of successful pioneering of which you have every right to be proud. May the next seventy of the Society be as fruitful.
>
> ORVILLE WRIGHT."

We have also received a cable from the Institute of Aeronautical Sciences, of which Mr. Orville Wright is such a distinguished member. It affords me great pleasure on this occasion to say how cordial our relations are with the youngest aeronautical society and to congratulate the youngster on its sturdiness and ability.

> "The youngest aeronautical society send greetings to the oldest aeronautical society on the occasion of its seventieth birthday. May we, in swaddling clothes, make obeisance before age and dignity. Our felicitations to Mr. Pye, one of our distinguished members, whose lecture before the Institute was exceptionally brilliant.
>
> LESTER D. GARDNER,
> *Secretary, Institute of Aeronautical Sciences.*"

Before introducing the distinguished lecturer of the evening I would remind you that this annual gathering takes place on what is, to the student of aeronautics, holy ground. We are seated under the very wings of the machine by which the long dream of human flight was at last realised. The duty of the aeronautical scientist was to develop to greater use the principles first applied successfully by the brothers Wright. As I am convinced that the destiny of aviation is to develop the wings of the dove rather than those of the eagle, I know that the pioneers of flying, chief among whom were Wilbur and Orville Wright, would always be held in honour for a benefit conferred upon mankind.

It is my pleasant duty to announce, following our custom, the awards made by the Council for the year 1934-35.

It is my very special pleasure first to announce that the Silver Medal of the Society has been awarded for the second time to Mr. B. N. Wallis for his work on the "Geodetic Construction of Aeroplanes." Mr. Wallis originally received the Silver Medal for his work on airship construction, so that he has proved himself a man of outstanding ability in two fields of aviation.

The next award is to Dr. Hugo Eckener of the British Gold Medal for his achievements leading to an advance in airships. Dr. Eckener is an outstanding figure in the world of lighter-than-air craft. He is at present bringing the Hindenburg across the Atlantic and I have received the following wireless message from him:—

> "Deeply regret impossible to be with you to-night. May I join with you in paying a tribute to the distinguished memory of Wilbur Wright and express my deep feelings of appreciation at the signal honour you have paid me by conferring the British Gold Medal for Aeronautics.
>
> ECKENER."

The British Silver Medal for Aeronautics has been awarded to Mr. A. J. Rowledge, the chief designer for Messrs. Rolls-Royce, for his outstanding achievements on aero engine design. He will be particularly remembered for his work on the Lion engine. Unfortunately Mr. Rowledge has been ill for some months and is unable to be present, and we all wish him a speedy recovery.

The Simms Gold Medal has been awarded to Mr. W. S. Farren, M.B.E., M.A., M.I.Ae.E., F.R.Ae.S., for his inventions of new methods of the measurement of drag and his designs of scientific apparatus for aeronautical research. Many of you have had the opportunity of seeing Mr. Farren's remarkable lecture illustrated by his smoke flow tunnel and other sides of his work which have visualised air flow.

The Taylor Gold Medal for the best paper read before the Society in the previous year has been awarded to Mr. E. F. Relf, A.R.C.Sc., F.R.Ae.S., for his paper on "The Compressed Air Tunnel." Mr. Relf is the Superintendent of Aerodynamics at the National Physical Laboratory, and I should like to congratulate him on your behalf for his well-deserved election as a Fellow of the Royal Society.

The Sir Charles Wakefield Gold Medal is awarded annually for any invention leading to safety in flying, an object of considerable importance in aviation. It has been awarded this year to Mr. C. R. Fairey, M.B.E., F.R.Ae.S., my immediate predecessor, for his pioneer work on and inventions in connection with the flap. The result of his work may be seen on many hundreds of machines flying to-day, though it was as long ago as May, 1916, when he took out his first patent.

The Busk Memorial Prize, founded in honour of the very distinguished member of the Society, is awarded for the best paper on some subject of a technical nature in connection with aeroplanes, including seaplanes, and has been awarded this year to Mr. R. P. Alston, B.A., F.R.Ae.S., of the Royal Aircraft

Establishment, for his paper on " Wing Flaps and other Devices as Aids to Landing."

The R.38 Memorial Prize Award this year has been awarded to Captain J. Morris, B.A., for his paper entitled " The Stressing of Rigid-Jointed Frames."

This year was the 70th anniversary of the founding of the Society. The exact date was January 12th, 1866. A special exhibition has been prepared, and I wish to thank publicly all those who have helped to make this exhibition as interesting as it is and particularly the Director of the Science Museum for his ready co-operation in allowing the exhibition to be shown here, and to Mr. J. E. Hodgson, our Honorary Librarian, under whose supervision it has been prepared.

I now come to the lecturer of the evening. The Wilbur Wright Memorial Lecture has been read by many distinguished people in aviation. Mr. Pye is not the least distinguished among them. He was trained as an engineer at Cambridge, and went as assistant to the professor of engineering at Oxford, and became a Fellow of New College. During the war he served as an experimental officer in the R.F.C. and R.A.F. at Orfordness and Martlesham, and after it carried on research work on engines and fuels in association with Mr. Tizard and Mr. Ricardo. He returned for a while to his old love, Cambridge, and became a Fellow of Trinity. In 1925 Mr. Pye was appointed Deputy Director of Scientific Research at the Air Ministry, a post he still holds. He is the author of one of the most important books published in English on the " Internal Combustion Engine." The aeroplane was the child of the internal combustion engine, the very life of which was lubrication, on which no one was better qualified to speak than the lecturer to-night.

The 24th Wilbur Wright Memorial Lecture read on May 21st, 1936, in the Science Museum, South Kensington.

SURFACE FILMS AND LUBRICATION.

By D. R. Pye, M.A., Sc.D., M.I.Mech.E., F.R.Ae.S.

When the Council of the Society did me the honour to invite me to deliver the Wilbur Wright Lecture I found myself in a dilemma. Many of those whose lives are concerned with engineering or with scientific research must feel, as I do, that after a certain stage they cease to be quite the real thing. The realities of the workshop give place to a daily round of files, reports and estimates, and the laboratory knows one only as a visitor.

When a man has entered upon this ink-stained path and is invited to give a public lecture, there are only two things he can do, except refuse. He must either plagiarise or generalise. Of the two, on grounds of morality, I prefer the latter; but it has the disadvantage common to most moral alternatives, it is much the more difficult. For myself, too, there is a further complication, because the field in which I might feel qualified to generalise would be on some subject relating to engines and their development.

Now you will not, I trust, misunderstand me if I suggest that to an engineer you could only be described as a very mixed audience, and I cannot persuade myself that I could say anything worth saying about engines, and at the same time serve it up so as to suit even a reasonable proportion of your palates. The reason is that the new things, the exciting things about engines are just those things which a mixed audience, supposing it was aware of their existence at all, would regard as trivial details, and certainly unworthy of an occasion like this; torsional vibrations in the crankshaft, for example, and the gumming of piston rings. The eloquence of Cicero could not make these sound appropriate to this hour and this company, and yet it is about them and their like that engineers will give up their sleep to talk and argue.

The reason why they are so exciting, to the man who lives with them, is because it is by such apparent details that a new design of engine succeeds or fails. It is not by a series of wonderful inventions that the modern engine, with all its harmonised complexity, has evolved from the quaint little objects now preserved under glass cases. Only in the mind of the inveterate patentee is a new engine conceived as something which can emerge in final and perfect form from the brain of its creator. Progress is rather by a gradual evolution, a steady series of trials, failures, modifications and further trials, as each step in the ladder of development is established, one by one.

Reflecting on this evolutionary process which, from the Wright brothers' little engine, weighing about 200lb. and giving less than 20 h.p., had produced in less than 30 years the Schneider Trophy engine with its 2,500 h.p., I could see one problem which must have remained a dominating preoccupation in the mind of every designer who has concentrated on the question of how to get more power for less weight. I refer to the problem of lubrication. I have not been able to discover that the pioneers Wilbur and Orville Wright, whose achievement of power-driven flight we commemorate this evening, made any special study of lubrication; but I have no doubt that during the early flights they gave many an anxious thought to the possibility of their engine seizing up through a failure

of the lubrication, and even to-day, although engine failures are rare, lubrication is so important an aspect of engine design that I need offer no apology for choosing it as my subject.

First let me say a word about the title. Why " Slippery Surfaces "?* Why not " The influence of mono-molecular films upon the contact phenomena of metal surfaces "?—for that is what I am going to talk about. Some friends have unkindly suggested that the choice was a flippant one. Not at all. The title is an intentional challenge to an attitude of mind which regards anything to do with scientific research as either unintelligible or merely funny. As a scientific society I conceive it to be our business, on our public occasions, to encourage the public to regard scientific research as what it should be: the shortest way of finding out quite ordinary things about the world we live in. The problem of lubrication is that of maintaining two surfaces slippery, one to the other, and I chose my title for this evening accordingly.

I shall take you far from engines this evening, for an attempt to understand the process of seizure and how to avoid it carries one at once into the realm of molecules, and of films on the surface of metals beyond the power of the microscope to observe. In many of its aspects we cannot even now be said to have got much beyond the stage of groping for clues to the riddle of what enables one surface to slide easily over another; but although we are still largely ignorant of what goes on at the ultimate points of contact, yet scientific research has obtained results of great interest which throw much light upon the nature and behaviour of an oil film on a metal surface. At the conclusion of the lecture I shall show you how very close we are, in these laboratory experiments, to some of the most pressing practical problems of the day.

When two surfaces slide past one another and are at the same time pressed together, the conditions between them may assume one of three quite different characters. The surfaces may be clean and dry, in other words unlubricated. When this is so, the friction and the heat produced will be high and there will always be some slight abrasion which may rapidly develop into a tearing up of the surfaces, known to engineers as a seizure. When a lubricant is present, it may be present in sufficient quantity to keep the metal surfaces entirely apart. When this is so, one surface may be said, as it were, to be floating past the other on a continuous film of oil, which is itself flowing between the surfaces. The load is supported by high fluid pressures in the oil. There is no actual contact of the metal surfaces, and the resistance to movement depends only on the viscosity of the oil. It is unaffected in any way by the nature of the surfaces or by the chemical nature of the oil. These are the conditions which obtain approximately in a well lubricated journal bearing and are typical of the " Michell " type of thrust bearing.

Thirdly, the surfaces may be subject to the condition known as " boundary lubrication," in which there is no free oil between the surfaces, and the friction depends not upon the viscosity of the oil, but upon the interaction of a few layers of oil molecules associated closely with the metal surfaces. Of this condition I shall have more to say presently.

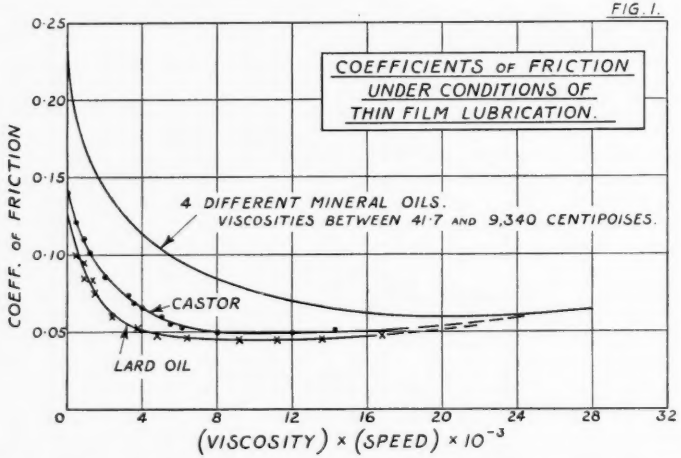
I shall not say much about fluid film lubrication. It is of the very greatest importance, but we should there be in a district which has been very thoroughly explored and is by now well mapped. The classical work of Osborne Reynolds (1), published just 50 years ago, laid the foundations of our knowledge of fluid film lubrication. The experiments of Beauchamp Tower (2), published a few years earlier, had demonstrated the existence of fluid pressure in the oil film in a journal bearing which varies in a regular manner from point to point and can reach a maximum value much higher than the mean load per sq. in. on the bearing; and Osborne Reynolds showed that the observations of Tower were in accord with calculations based on the known laws of hydrodynamics.

* This was the title of the lecture as delivered.

Since that date the subject has been developed on the theoretical side by Rayleigh (3), Martin (4), Harrison (5), Sommerfeld (6), and experimentally by Stanton (7), Boswell (8), and many others (9). The subject is rendered fascinating by the way in which mathematics and experiment go hand in hand; so completely, in fact, do they do so, that there is more interest in following some of the newer paths of investigation, of which we cannot yet see the end. I shall content myself, in regard to fluid lubrication, with an example to show how thin the layer of fluid between the surfaces can be, while still retaining all the characteristics of a flowing film.

In some experiments by Stanton (7) using a circular shaft of 1in. diameter, revolving inside a loaded bearing, the minimum thickness of the film which is near, but not at, the highest point, was calculated to be about 0.00005in. This means that if the 1in. shaft were magnified 200 times, till it was about 16½ft. in diameter, the oil film would even then be only 1/100in. thick.

FIG. 1.



That is a very thin film, but when considered in relation to the size of the oil molecules, we find that the solid surfaces of the shaft and its bearing were still so far apart as to be quite without influence on the friction, which was found to depend, not on the nature, but only on the viscosity of the lubricant. There was room between the boundaries of that very thin film for 4,000-5,000 molecules, and the influence of the solid surfaces would not be felt by molecules beyond the second or third layer from the surface.

Now let me show you the results of some experiments of a different kind, in which the flowing film is not maintained. These experiments (10) were made at the Bureau of Standards in Washington with a machine in which three small cylindrical rollers are held *fixed* in a horizontal circular plate with their axes radial and horizontal. The stationary rollers are pressed on to a flat circular track which can slide under them. When stationary the rollers make only line contacts with the track if there is no oil, and when lubricant is present they sink down through it until there is nothing at the line contact but a film of infinitesimal thickness. When making an observation the track is rotated at a steady speed, and the force of friction between the track and the rollers is measured for various vertical loads on the latter.

Some typical results are illustrated in Fig. 1. The upper curve represents those obtained with four different mineral oils of viscosities varying as widely as from 42 to 9,340 centipoises at 25°C., while the lower curves are for two fatty oils.

When the speed, or the viscosity of the oil, or both, are high, the film under the sliders is comparatively thick, and the coefficient of friction tends towards the same value, whatever the oil, for a given value of the product (viscosity × speed).

At slow speeds and low viscosities, however, a condition of boundary lubrication is approached in which the surfaces are intermittently in contact, or protected only by a few layers of oil molecules. In these circumstances the nature of the oil has a marked effect upon the friction, as is shown by the separation of the lines in Fig. 1. It will be seen that the coefficient of friction for the two fatty oils is about half of that for the mineral oils at the same value of the product (speed × viscosity). At very low values of the speed and viscosity, there may be no more than a single layer of oil molecules, called the "primary" layer, on the track, and on the slider, the molecules in each of these primary layers clinging firmly to the metal surface. For reasons to be given later, one reaches the conclusion that as sliding proceeds these primary films are subject to a very rapid series of breakdowns and repairs, and that the observed coefficient of friction is an average result derived from a rapidly alternating state.

It is characteristic of the condition of boundary lubrication that the friction depends not only on the kind of molecules which compose the lubricant, but also on the nature of the solid surfaces. The behaviour of the oil molecules in the primary layers is profoundly affected by the forces of molecular attraction exerted upon them by the molecules of the metal surface.

I am going to give you a familiar mental image to help to picture these primary layers of lubricant upon a solid surface. If a steel ball of $\frac{1}{2}$in. diameter covered with a single layer of oil molecules were magnified one thousand million times, which would make it the size of the earth, the primary film of oil upon its surface could be pictured like a well grown crop of wheat stretching without a break across the plains of Canada on the Middle West.

Perhaps it may surprise you that I should compare an oil film with something so typically upstanding as a crop of wheat; but the choice of simile was deliberate for it may be pressed beyond the mere thickness of the covering of the earth's surface. Although we cannot see individual molecules, we yet know a great deal about their shape and behaviour, and it is one of the oddest conclusions of modern research that the molecules of the good lubricants are long and thin, and that they all tend to stand up at right angles to the metal surface. The simile can be pressed further yet, for the thickness and behaviour of the film depends upon the nature of the solid surface—in other words, upon the fertility of the ground and the kind of roots which the oil molecules put down into it.

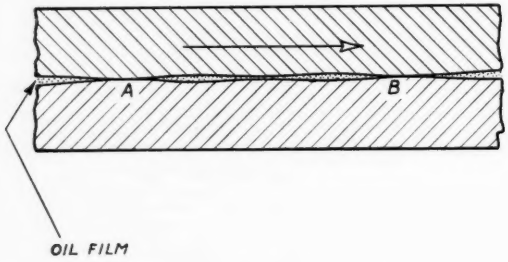
Before discussing the great influence on surface friction of these primary films only one molecule thick, I must say something of the nature of metal surfaces and of what causes friction between them. It used to be thought that the force of friction which opposes the sliding of one surface over another, was always due to a sort of interlocking of minute asperities at the points of contact, however perfectly the surfaces might be polished. That view is now given up,* and we believe that the resistance to motion is due to cohesive forces between the molecules themselves acting across the interface between the surfaces; and that these forces are of the same kind as the cohesive force between the molecules of a solid on which its strength depends, or as the cohesive force that enables a drop of water to cling to a glass rod. Why, you may ask, if that is so, do not two pieces of steel join themselves together when the two flat surfaces are pressed one to the other? The answer is probably threefold. In the first place there is the contamination of the surfaces by extraneous films, of which I shall have more to say presently. Secondly, the cohesive forces between the

* Hardy showed that the value of the friction between two "optically" perfect glass surfaces is the same as with ordinary plate glass; and that each of them actually gives a higher coefficient of friction than with ground glass surfaces, probably because of the impossibility of cleaning the latter so well.

molecules are very powerful at short range, but the range is extremely small, and even when the surfaces are made as flat as it is possible to do, it is only over a small fraction of the apparent area of contact that the molecules in the two surfaces are brought within each other's range of attraction. In a sliding motion the average number which are within range, and therefore the friction force, remains fairly constant, but in pulling apart two surfaces which are pressed together, it is impossible to pull equally, even on the small number of molecules which are close enough to cohere to one another. We shall always overcome the molecular forces successively, and for this reason they are quite imperceptible.

Tomlinson (11) has developed an interesting theory to explain the existence of the tangential force. Having made certain assumptions about the way in which the attractive and repulsive forces between individual molecules vary with distance, he has shown how the sliding friction between two solids should be related to their elastic constants. The quantitative conclusions derived from the theory, however, cannot be said to agree more than very roughly with experiment (12). This is not surprising, having regard to the probable unevenness of all experimental solid surfaces when judged in terms of molecular dimen-

FIG. 2.



sions, and one must conclude that the physical processes on which the force of friction depends are too complicated to allow of their being expressed by a theory based on the behaviour of individual molecules. In the present state of knowledge we must be content with a more crude mental picture such as Adam has suggested, according to which a sliding motion is accompanied by a very rapid succession of weldings together and tearings apart between groups of molecules, wherever they are brought into sufficiently close contact.

Any surface, solid or liquid, is composed of molecules in motion, and a perfectly smooth surface would be one in which any irregularities were of molecular dimensions. We can picture the free surface of an undisturbed liquid as being smooth in that sense. It was the view of Lord Rayleigh that the difference between a liquid and a finely polished solid surface was not great, and that elevations on the solid surface would be of molecular dimensions. At the same time it must be remembered that our finest test for the flatness, as distinct from smoothness, of a surface would only detect hills and valleys equal to a height of about a thousand molecules. While accepting Rayleigh's view, therefore, that the smoothness of a solid surface may approach that of a liquid, we may yet picture the most perfectly prepared plane surface as rather like a good golf green, smooth, but with ups and downs; and almost any bearing surface met with in engineering as being like a piece of smooth rolling downland. Fig. 2 is intended to give some idea of what two supposedly flat surfaces, pressed together with an oil film between, would look like if sufficiently magnified. They touch only at the two points A and B.

The existence of the ups and downs is of great importance in the study of lubrication, for it means that as the surfaces slide past one another, the points where there is contact between the primary films on the hilltops are constantly changing, and that they are separated by flooded lowland areas where the film is thick enough to contain many thousands of molecules, and where the laws of fluid friction will hold good. The danger of seizure, following a breakdown of the primary film, would depend upon the rate at which heat is developed at the hilltops, where the friction is comparatively high, and how long the film on any one hilltop remains in contact with that on another before it is relieved by being cooled in the neighbouring flood. It is important to observe, at this point, the rôle played by the viscosity of the lubricant as a safeguard against seizure. So long as the primary films on the hilltops are in contact, viscosity plays no part at all, and the only factor of importance, apart from the normal force pressing the surfaces together, is the coefficient of friction between the primary films. But as two hills approach one another the oil film has to be squeezed away to another part of the surface, and how quickly this will happen depends upon the viscosity of the oil. It follows, therefore, that high viscosity will reduce the length of time during which boundary conditions exist between each pair of hilltops and hence the danger of breakdown due to heating up of the film.

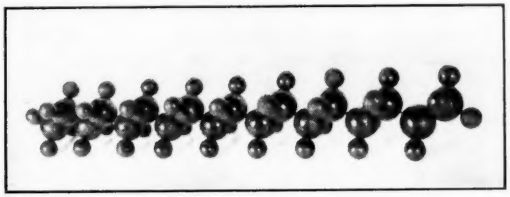


FIG. 3.

Photograph of a model showing the spacial relationship of the carbon and hydrogen atoms in a "straight-chain" hydro carbon molecule of the paraffin series.

Now about these primary films and how they affect the slipperiness of a surface. Such films may be of many different kinds, but those in which we are interested are composed of oil molecules, and it is first necessary to have a mental picture of what these are like. Although we cannot observe them directly, the methods of the chemist, aided by those of X-rays and electron diffraction, have told us almost as much about their form and behaviour as if we could see them. They are for the most part built up of simple chains of carbon atoms to which hydrogen atoms are attached, or of these chains associated with similar hydrocarbon groups joined together in a ring formation. The peculiar looking object illustrated in Fig. 3 and somewhat reminiscent of the art of Mr. Walt Disney, is a true to scale model of a simple hydrocarbon chain of the paraffin series magnified 165 million times. The model is 15in. long. Notice the carbon atoms represented by the larger spheres, related to one another in a zigzag pattern, each, except the end ones, with two hydrogen atoms attached on alternate sides. This simple chain is symmetrical, end for end, and the ends are composed of CH_3 groups which are relatively stable and inactive. The molecule is illustrated diagrammatically at (*a*) of Fig. 4. Some molecules have chains which end in the hydroxyl (OH) or carboxyl (COOH) groups, and the molecules are rendered chemically active by these less stable end-groups. The molecule of palmitic acid, for example, has the stable CH_3 group at one end and the chemically active COOH group at the other. Palmitic acid is an excellent lubricant. It improves the oiliness of any oil to which a small quantity is added. The molecule of

ricinoleic acid, which is present in castor oil, is shown diagrammatically at (*b*) in Fig. 4. This molecule, besides having the carboxyl group at one end has two other points in the carbon chain at which the chemical valences of the carbon atoms are unsatisfied and where in consequence the molecule shows an increased tendency to chemical activity. These are the positions of the " double-bonds." In each of these fatty-acid molecules the hydrocarbon chain is loaded at one end, as it were, by a group in which the chief chemical activity of the molecule resides. When a molecule is rendered unsymmetrical by having chemically active groups at one end, it is characterised as polar. It has been found that the substances which are the best lubricants under boundary conditions all contain molecules with this polar character, that is, they are of a type in which the end-groups of the hydrocarbon chain are different, one being chemically inactive, and one active.

FIG. 4.

THE CONSTITUTION OF LUBRICANT MOLECULES.

(a) $CH_3\left[CH_2\right]_{16}CH_3$

A 'STRAIGHT CHAIN' PARAFFIN.

(b) $CH_3\left[CH_2\right]_5 CH.OH.CH_2.CH = CH.\left[CH_2\right]_7 C\overset{O}{\underset{OH}{}}$

CHEMICALLY ACTIVE END

RICINOLEIC ACID, PRESENT IN CASTOR OIL IN THE FORM OF A GLYCERIDE.

Studies of oil films deposited on water, chiefly by Langmuir (13) in America and Adam (14) in this country, have proved conclusively that it is possible to produce a single layer of oil molecules on the surface of clean water, and by crowding the molecules up into a smaller and smaller area of the water surface, it is possible to demonstrate the point when they reach the condition of being as closely packed in their single-layer film as they can go, so that, with any further compression, the molecules begin to climb on each others' backs and form a double layer. In the close packed single layer, the forces with which the molecules repel one another have been measured, and also the average area occupied by each molecule, that is, its cross-section. All the hydrocarbon chains have been found to have very nearly the same cross-section, equal to 21×10^{-16} sq. cm. The lengths of the lubricant molecules vary between 20 and 30×10^{-8} cms. It has also been proved that when the molecules forming the close packed layer are of a strongly polar character, they always tend to arrange themselves standing up perpendicular to the water surface with the active ends downwards.

The ability of molecules to form films of this type on water is considered to be the result of a balance between the force of attraction exerted by the water molecules upon the polar groups at one end of the oil molecule and the mutual attractions between the rest of the oil molecules, *i.e.*, between the hydrocarbon chains. This mutual attraction between the main bodies of the oil molecules is

sufficient to make them remain as a continuous film on the surface, and to resist their being drawn down into the water by the pull of the latter upon the carboxyl groups at one end. If their mutual attractions did not hold the oil molecules as a film on the surface, the oil would have the character of a liquid which is soluble in water, as, for example, glycerine is. Molecules with one or more "double-bonds," instead of standing up straight from the water surface, as palmitic acid does, have been shown to have additional points where they are drawn down to the water surface, namely, at these points of unsatisfied valency in the hydrocarbon chain.

From this study of films formed on the surface of water, we turn to films formed on solid surfaces (15). Here, as for the water films, the substance of which a film is to be formed is dissolved in some very volatile solvent like ether or benzine. The solution is made so dilute that one drop, after spreading over a given area of the metal surface, will evaporate and leave behind it just enough oil molecules to form a mono-molecular layer.

If gold is beaten out into an extremely thin leaf, so thin that a fine pencil of electrons projected at it can pass through, the pencil is split up by diffraction so as to form a regular pattern, it then falls on a photographic plate. The pattern depends on the arrangement of the atoms in the gold leaf, and is always the same for that metal and different for other metals. When a mono-molecular film was deposited on the gold, there appeared, in addition to the gold pattern, a series of rings and spots which could only have come by diffraction of the pencil of electrons through a layer of molecules all packed parallel to one another and at right angles to the metal surface. Here, therefore, we reach, by a totally different method, a conclusion identical with that arrived at by experiments with films on the surface of water. And, moreover, just as an oil without active groups such as a normal paraffin gave no evidence of orientation at right angles to the water surface, so, when the films deposited on the gold leaf were composed of molecules which were symmetrical end for end, they oriented themselves flat on the surface, and no electron diagram appeared.

You see now my reason for the simile of the crop of wheat. These long oil molecules quite literally take root at one end in the metal surface (adsorption the chemists call it) and it is upon the strength of its roots, and the suitability of the soil for retaining them, that the strength of the primary oil film against rupture by friction depends.

The relationship between the molecules in two primary films when the surfaces are in contact and under an external load is at present a matter of pure speculation. It is known, however, that the hydrocarbon chains are flexible, and that the cohesive forces between the atoms within a chain are far greater than the forces of attraction between neighbouring chains. Furthermore, when the atoms in one chain come within a certain range of those in another, very large repulsive forces must come into play. When the high spots in a pair of sliding surfaces approach one another it is therefore not illegitimate to picture the primary layer of lubricant on one surface as lying over in the direction of motion of the other, just as a wheat crop bends to the wind sweeping over it. The surfaces approach until the hydrocarbon chains of the lubricant molecules, lying nearly parallel, now, to the surfaces, come within each other's range of repulsive forces, which are equal to the external load pressing the surfaces together.

If this were a complete picture, the frictional force would have to be considered as being due to attractions between the hydrocarbon chains in a tangential direction, co-existent with the repulsions normal to the surface. Some experiments, however, to be described presently, make it nearly certain that so long as a state of boundary lubrication continues between two surfaces the primary films must be imagined as undergoing a continuous and very rapid succession of ruptures and repairs; and it is possible that if it were not for this rupturing of the films the frictional force would be so small as to be imperceptible.

For the purposes of observation and measurement, the films I have described on water and gold leaf have to be carefully prepared, but these invisible films are much more prevalent than you may suppose. In fact, you cannot escape from them. It is not too much to say that a really clean, uncontaminated surface is a thing practically unknown in nature. You break a piece of anything in air, and instantly the broken surfaces are covered with a film of oxide or of any other molecules which may happen to be in the neighbourhood. Such a film is sufficient to alter completely the ultimate nature of the surface and to prevent the molecules at the broken surface from cohering again, even if the surfaces could be perfectly fitted together.

Although they could hardly be called lubricants, the great majority of these contaminating films are of a nature to reduce the friction between smooth surfaces. Many of you may be familiar with the embarrassing manner in which a teacup will slide about in a dry saucer, and you may have learnt by experiment that a drop of hot tea will make it stick. The study of surface films may almost be said to have sprung from this homely observation, for it exercised no less a mind than that of the great Lord Rayleigh (16), and he refers to earlier discussions with Lord Kelvin. The explanation is that even in the best regulated household it is normal for the supposedly clean, dry cup and saucer to be covered by a grease film, which is dispersed by the presence of water. The film is quite invisible, and Hardy (17) showed that it was not even necessary to touch the surface in order to produce it. When a clean metal surface was exposed to the vapour of a lubricating oil, the molecules gradually assembled and arranged themselves on the surface, reducing the observed coefficient of friction as they did so, until by condensation from the vapour of the oil, an invisible film was formed which gave exactly the same coefficient of friction as when a pool of the same oil was placed on the surface.

It is the existence of these self-deposited films which makes it so very difficult to obtain consistent results in experiments on friction and lubrication, because it is only with the most elaborate precautions that you can be certain that the surfaces you experiment with are the same in successive experiments. Hardy showed that when sufficient precautions were taken, then the same two substances always gave exactly the same coefficients of friction. His test of success in the cleaning of the experimental surface was a gradual rise of the coefficient of friction to a high and constant value, as the casual and unwanted films were removed. After a uniform condition of the surfaces had been established, the effect of different kinds of lubricating films upon them were entirely consistent, and very surprising results were revealed.

It should be noted in passing, that even surfaces clean to the point of giving a high and constant friction coefficient would not be clean in the sense of being the same as a surface freshly produced by fracture. Our so-called clean surfaces are probably covered with oxide, or other films natural to the particular material, so adherent as to be always there after the first moments of exposure. It has been found, for example, that the molecules of a steel surface fractured under mercury will amalgamate with the mercury, but if the fracture is made in air, and the surface then plunged into mercury, amalgamation does not take place.

Fig. 5 illustrates some of the results obtained by Hardy (18), when the cleaned experimental surfaces were lubricated with different types of pure chemicals. The observed coefficient of friction falls in a strictly linear manner with the molecular weight, *i.e.*, with the length of the hydrocarbon chain in the molecule. The rate of fall is more rapid, and the absolute value of the coefficient of friction is less, for substances with more strongly polar molecules. Hardy's were experiments on static friction, in which the force measured was that just necessary to start the sliding movement between the surfaces. But you will remember the parallel results, shown earlier, in which the coefficient of kinetic friction was substantially less with the two fatty oils, castor and lard oils, which contain strongly polar molecules, than with the mineral oils which are only weakly polar.

I come now to a further series of very recent experiments on kinetic friction of great interest which will serve as a bridge to bring my lecture back from the world of molecules to engineering, and enable me to conclude on a more practical note.

FIG. 5.

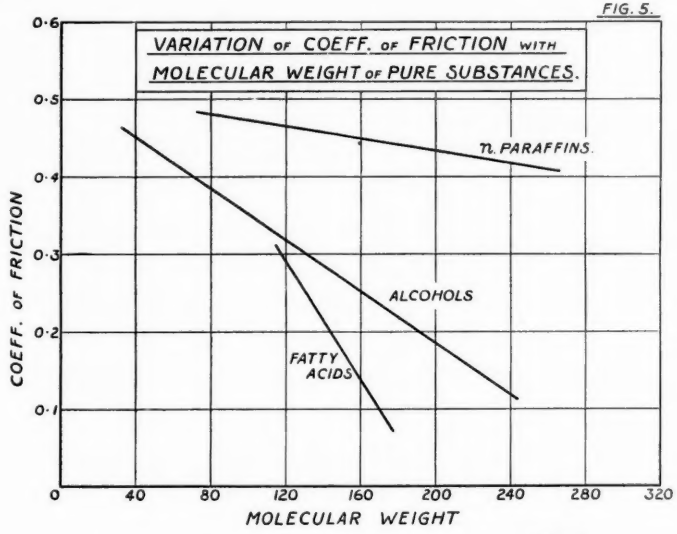
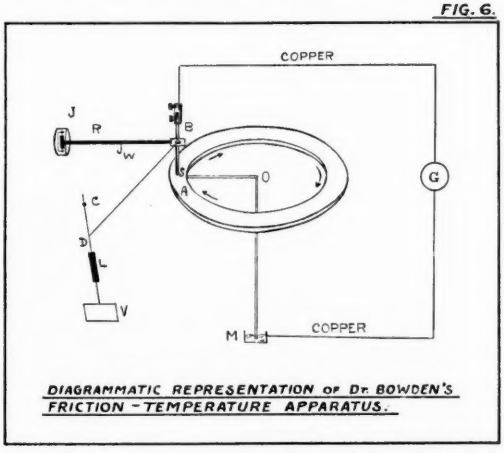


FIG. 6.



By courtesy of the Royal Society.

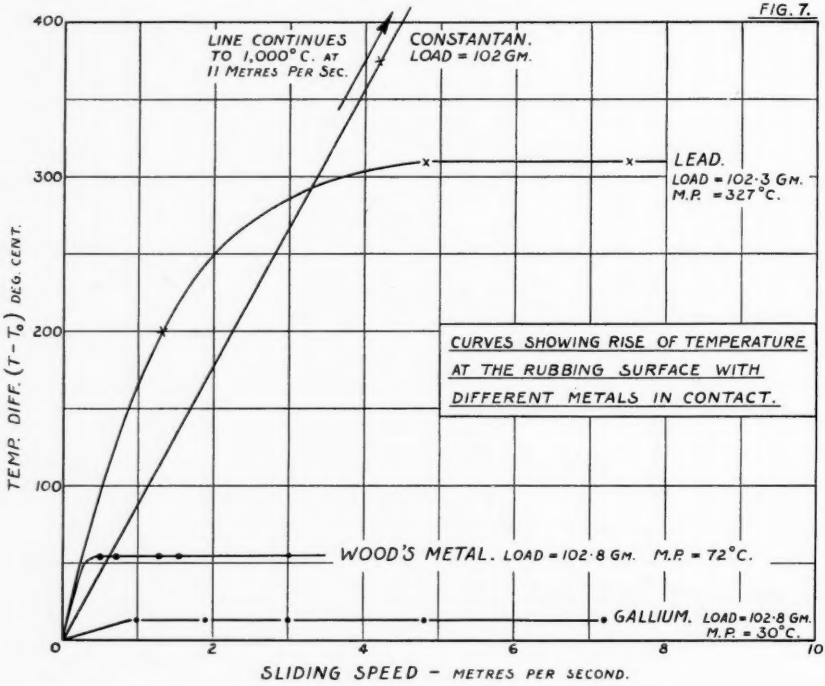
When two wires of certain dissimilar metals are joined in a loop, and one of the junctions is heated above the other, an electric current flows. The heated junction is acting as a thermocouple. Dr. Bowden (19) has made use of this well-known effect to measure the temperature produced by friction, when one metal surface rubs upon another; and he has found that the temperatures produced may be astonishingly high.

Fig. 6 illustrates the principle of his apparatus. The rotating circular metal track A is polished on its top surface, and a pencil of the dissimilar metal B presses down on the circular track at the point S. The force of friction on the

pencil can be measured by a delicate pendulum arrangement when the disc is travelling at a known rate, and this enables the heat produced to be calculated. It is possible to deduce theoretically that very high temperatures should be produced at the surface, and that these temperatures would fall away rapidly with the distance from the rubbing contact. The exciting fact to us, as engineers, is that Dr. Bowden has shown that these high temperatures do in fact occur in the surface layers.

I have only time this evening to draw attention to two essential points in this research. Firstly, the proof that the temperatures indicated by the electrical effect of rubbing one metal surface on another are *real* high temperatures, which exist at the surfaces, although the rest of the metal remains perfectly cool. Secondly, the experimental proof that these high temperatures are confined to exceedingly thin surface layers of the metal.

FIG. 7.


400
300
200
100
0
2
4
6
8
10
TEMP. DIFF. $(T-T_0)$ DEG. CENT.
SLIDING SPEED – METRES PER SECOND.
LINE CONTINUES TO 1,000° C. AT 11 METRES PER SEC.
CONSTANTAN. LOAD = 102 GM.
LEAD. LOAD = 102·3 GM. M.P. = 327°C.
CURVES SHOWING RISE OF TEMPERATURE AT THE RUBBING SURFACE WITH DIFFERENT METALS IN CONTACT.
WOOD'S METAL. LOAD = 102·8 GM. M.P. = 72°C.
GALLIUM. LOAD = 102·8 GM. M.P. = 30°C.

$T_0 = 17°C.$

For any two metals the heat produced, and therefore the rise of temperature at the surfaces, should be proportional to the speed and to the normal force between the pencil and track. The curves on Fig. 7 show the way in which the rise of temperature increased as the speed was increased, while a constant load was maintained on the pencil. The four curves are for pencils of four different metals on a mild steel track. I have included only one curve for each metal, although several with different loads on the pencil were taken. Each curve represents a series of observations at increasing speeds.

With the constantan pencil there was a steady increase of temperature proportional to the speed, until at the maximum speed of 11 metres/sec. the temperature difference was over 1,000°C., far beyond the limits of the diagram, but below, it is to be noted, the melting point of constantan, which is 1,290°C.

Now comes the result of especial interest and importance. The other three are all metals of comparatively low melting points. At first there is the same rise of temperature with increasing speed as with constantan, but quite suddenly the curves become horizontal, and further increases of speed produce no further rise of temperature. The temperature at which the curve becomes level is in every case the melting point of the metal as determined by melting it in bulk. The three curves are for lead, melting at 327°C., an alloy known as Woods metal, melting at 72°C., and the metal gallium, melting at 30°C. There was, of course, no *apparent* melting of the pencil whatever. The rise of temperature was confined to an exceedingly thin layer at the rubbing surface, but the fact that it always reached a limit at the well-known melting point of the metal used is sufficient evidence to dispose of any doubt about the reality of the temperatures observed.

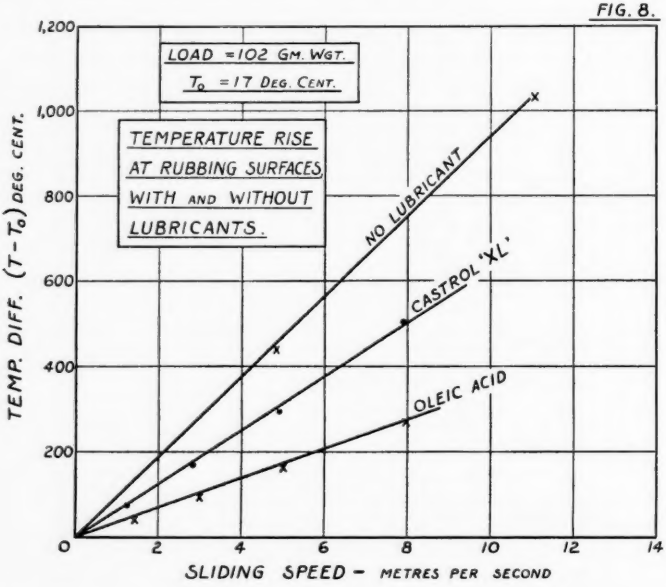
Further evidence of the extreme thinness of this heated layer was obtained in the following way. It was noticed that if the track was made of a slightly harder material than the pencil, and was rotated at constant speed, with a constant load on the pencil, then, instead of the galvanometer indicating a constant temperature, there was quite a rapid fall of temperature from the maximum, which was recorded when the circular track was freshly cleaned. On the other hand, if the pencil was moved slowly in a radial direction, so that instead of going over and over the same circular track, the pencil moved along a spiral track, there was no drop of temperature. The explanation is obvious. The thermo-electric effect depends upon the temperature at the surface of separation between the mild steel track and the metal of the pencil. When both are clean the surface of separation is the rubbing surface. But as soon as the smallest film of the pencil metal had been rubbed off on to the steel track, the heat produced by the friction had to be conducted through this film of metal to the thermo-electric surface of separation. And this caused a substantial drop in the measured temperature, even when the film left upon the track was far too thin to be measured, almost too thin to be perceived at all.

These results, for dry polished surfaces, are of scientific, rather than practical interest. But the next figure will show you that even when the surfaces are kept lubricated the temperature can reach very high values.

The straight lines in Fig. 8 show results of the same type as in Fig. 7, but all with the constantan pencil and the same load of 102 grammes weight. The upper line is the same as the line for constantan in the last figure, but drawn to a smaller scale and showing the temperature observation of over 1,000°C. at a speed of 11 metres/sec. At a speed of 8 m. per sec. the temperature when unlubricated was 750°C., but ample lubrication with one of the best of the well-known oils only reduced this to 500°C. The track under these conditions had the appearance of a perfectly lubricated surface, and there was, of course, no perceptible rise of temperature anywhere, except that indicated electrically as existing at the rubbing surface. We are faced, then, with the conclusion that even between two cool and lubricated metal surfaces, the local effect of friction upon the surface molecules may be to raise them to a state of motion corresponding almost to a red heat, and well above the decomposition temperature of the oil. If this is correct, one cannot avoid the further conclusion that as soon as boundary conditions occur, there is a danger of local breakdown of the film and that when the condition persists for any length of time, the primary films of the lubricant on the metal surfaces do not remain intact, but are continuously being destroyed and repaired as sliding proceeds. Happily for engineers, the persistence of a state of boundary lubrication at any one point is, for reasons already given, comparatively rare in machinery, else would our problem be far more harassing than it is; but as the high points of the surfaces approach and recede from one another, so is there the ever repeated likelihood of these high surface temperatures and of a momentary rupture of the essential primary films which prevent seizure.

What, then, are the lessons which we, as engineers, can draw from these studies of the nature of slippery surfaces? That friction and metallic cohesion, in the first place, are essentially similar, depending as they do on the same inter-molecular forces of attraction. This is of especial interest in connection with certain experiences with aero engine bearings, in which there was visible evidence of minute adhesions having taken place between the shaft and bearing metals, without these having proceeded to the point of seizure; an observation entirely in accordance with Hardy's conclusion that molecular attraction causes the particles of rubbing surfaces to cohere, with a tenacity equal to that of the metal itself, whenever the molecules approach close enough to one another; and that metallic wear only takes place where real molecular contact can occur. The experimental evidence is that a sliding of one surface on another will always

FIG. 8.



cause some slight abrasion, due to this metallic cohesion, unless the surfaces are protected by a layer of oil molecules. Even when they are so protected, temperatures are produced in the surface layers so high that we have to imagine an extremely rapid succession of breakdowns and repairs of the film. It may be that the force of friction, once complete fluid lubrication has ceased, is due to the cohesion and parting again of innumerable pairs or groups of molecules, and that the observed value of the force is really an average result derived from a rapidly alternating state. You can picture what happens as though a liner were sliding forward along the quayside at parting, every deck-level and porthole crammed with passengers, each with near relations in rows at his own level on the quay, and each insisting on holding hands as long as possible, till he is pulled apart, thereafter to grasp the hand of the next. If the number of passengers is large enough the liner will feel only a steady drag against her motion, even although the hand-grip of some passengers will be many times stronger than of others.

Viscosity is important in a lubricant because, between uneven surfaces, the time taken to squeeze away a more viscous oil and establish this dangerous state of boundary lubrication between two high spots, is greater than with a less

viscous, and the period of boundary lubrication is therefore shorter. A powerful primary film is a safeguard against seizure and depends upon the happy union of a strongly polar molecule with a receptive surface. The nature of a bearing material is therefore of importance not only from the point of view of its physical properties, such as hardness, etc., but also of its chemical properties, in so far as these affect its power to form adsorbed films.

Chemical stability of the lubricant molecules up to high temperatures is clearly of vital importance. This is no new doctrine, but we have in the past been in the habit of testing oils for chemical stability at about 200°C., a figure based upon the probable working temperature of the oil near the piston. It may be that Dr. Bowden's results mean that we must look for the power of an oil, or at least of some small fraction of it, to resist breakdown up to much higher temperatures, of the order of 600°C., although we never expect such temperatures in the bulk of the oil as a whole.

Failing this, the line of advance may be by the preparation of the solid surfaces in such a form as to resist any mutual cohesion of the molecules across the interface at the moments of breakdown of the primary films. The cohesive forces which are fatal to a bearing are essentially the same as the forces of chemical affinity, and just as the elements show a wide diversity in their eagerness to form chemical compounds with one another, so bearing surfaces must differ in their readiness to cohere when lubrication has failed. In this connection graphite is interesting, both scientifically and practically. Graphite is a form of carbon in which the carbon atoms build themselves up into thin flakes. The methods of electron diffraction have shown that when a surface is covered with graphite in which the flakes are all lying flat, then the coefficient of friction is low and we have that comparative rarity, a slippery surface without oil. If the graphite flakes, however, are arranged at random on the surface, the lubricating value is lost.

Cast iron is well known for its good surface qualities. Now cast iron contains minute particles of free graphite, and examination by electron diffraction has recently shown that rubbing a cast iron surface has the effect of bringing out the occluded graphite flakes and spreading them over the surface, where they act as a lubricating layer protecting the iron from abrasion. On a steel surface no such layer can be obtained, because steel contains no free graphite, but the same method of electron diffraction has yielded other results of great interest.

Normally the surface of a metal is composed of an agglomeration of minute crystals. When this is so, although the crystals are arranged at random, sufficient magnification would always show the atoms arranged in a regular " space lattice " of definite geometrical form, essentially different from the amorphous condition which is typical of a liquid. The researches of Beilby showed that polishing can destroy the essential crystalline nature of a metal surface and produce the amorphous " Beilby layer " in which the atomic arrangement is as formless as a liquid. The running-in process on a steel aero engine cylinder was found to have changed the nature of the surface from that of a random crystal structure to a typical " Beilby layer " of considerable depth. Some remarkable properties of these amorphous surface layers on a metal have been observed by Finch (20) and others. A minute sprinkling of crystals of another metal, for example, deposited on the amorphous surface can be dissolved by the surface layer just as though it were a liquid. If several successive sprinklings of crystals are applied, the amorphous layer becomes saturated and refuses to dissolve any more. This solution of one solid metal by another solid metal takes place at ordinary room temperature, and in a few seconds; but it is only the amorphous " Beilby layer " that will act in this way as a solvent. I mention this interesting experiment because it suggests how profoundly the physical properties of a surface may be altered by so ordinary a treatment as polishing, and because it shows that we may be only at the beginning of knowledge about the treatment of metallic surfaces for the reduction of friction, or rather, I would say, for the

avoidance of seizure. The working value of the friction in an engine will be determined mainly by the properties of the lubricant; but if we are right in believing that under boundary conditions there is a constant succession of breakdowns and repairs of the primary films, then it is evident that if a treatment can be found for the underlying metal surfaces which renders their molecules less inclined to cohere together and form minute abrasions, that treatment will diminish the danger of seizure and allow of the sliding surfaces being at a higher temperature.

The power which an engine of a given size can produce depends upon how much air and fuel you can feed it with per minute. Each pound of air supplied by the supercharger means so much power at the crankshaft. But it also means so much waste heat distributed about the engine, and this must be got rid of as fast as it is received. The result is that progress in the struggle to get more power for less weight has meant ever-rising temperatures in the moving parts of the engine, and in the lubricating oil which keeps them slippery, one to the other. Perfect lubrication is vital to the life of an engine, and the demands made upon the oil, as powers increase, become ever more severe. There is no doubt whatever, to my mind, that the problem of the slippery surface, and how to maintain it under the extremely arduous conditions of the modern engine, is likely to dominate design and even to become the chief limiting factor in engine development.

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The Chairman: Of the twenty-three previous Wilbur Wright Memorial Lectures some had been good and some not so good. Mr. Pye had been to them all, and had benefited thereby, which explained how he managed to talk up to his subject and down to his audience. He hoped that the Secretary of State for Air, who was present, would be able to turn the knowledge gained to some account in his high duties. All present knew that alcohol was a better lubricant than some other things, a fact some had suspected before, and facts had emerged about contaminating films which might no doubt be turned to the good of the country. He proposed a hearty vote of thanks to the lecturer and would ask Mr. Fairey, the Past-President, to second the vote.

Mr. C. R. Fairey *(Past-President)*: Mr. Pye had shown a most admirable handling of a very difficult task and he had the warmest appreciation for the skill with which he had carried out his task. The vivid accounts given by Mr. Pye of the suspected heat generated when two surfaces were rubbed together might enlighten many of those present concerning the phenomena which arose when an aircraft constructor came into close contact with the Air Ministry. He had the greatest possible pleasure in seconding the vote of thanks.

The vote of thanks was carried with acclamation.

FORMULÆ AND METHODS OF CALCULATION OF THE STRENGTH OF PLATE AND SHELL STRUCTURES IN AEROPLANE CONSTRUCTION.

By O. S. Heck and H. Ebner.*

I. Introduction.

The object of the present report is to make a general survey of the simple formulæ and methods of calculation for the determination of the strength of thin-walled structures (plate and shell structures) which are increasing in importance in aeroplane construction, and to facilitate the study of original papers by adding a detailed list of relevant literature. An essential characteristic of the sheet metal covered structures in question is, that the metal skin in addition to the stiffening elements participates in the transmission of force. Structures in which the metal sheet serves merely as a covering but which is not loaded in accordance with its strength, do not come within the scope of the present considerations. Non-stiffened and stiffened plates and shells, mostly of very small wall-thickness (about 0.5 to 1.2 mm.) may be regarded as structural elements in plate and shell structures (especially shell fuselages, " monocoques " and wings). The solution of the stress problem in constructions of this kind is less important than the question of stability and in particular the supporting capacity of a structure after exceeding the limit of stability. The question of resistance to buckling or bulging of profile bars will not come within the scope of the present paper, although the buckling stresses of the stiffeners alone, *i.e.*, as independent pressure bars are frequently applied for the determination of the supporting capacity of a plate or shell construction.

The material dealt with is divided into three main elements of a plate or shell structure, viz., strength of (1) the rectangular plate; (2) the circular cylindrical partial shell (circular cylindrical shell segment); (3) cylindrical solid shell (continuous circular cylinder shell). These elements are further sub-divided into isotropic, orthotropic (orthogonal-anisotropic) and stiffened plates or shells. Orthotropic plates and shells, which possess different but invariable stiffnesses in two directions perpendicular to each other, are, for example, plates or shells made of plywood and, strictly speaking, also of rolled sheet metal with moduli of elasticity differing in the direction of rolling and perpendicular to it. In many cases stiffened plates and others made from corrugated sheet may be treated approximately as orthotropic plates, by substituting constant mean stiffness for the periodically variable stiffnesses in the direction of the stiffeners (at right angles to each other). The material may be further sub-divided according to the nature of the stress in the structural element concerned.

In addition to the mathematical formulæ, a reference is nearly always given to the results of experiments. When applying mathematical formulæ for the strength of thin-walled structural parts, particular attention must be given to see whether, and to what extent, they have been proved by experiment. Experimental values often differ widely from the calculated values. In particular in the case of investigations on the stability of very thin unstiffened plates and shells, inevitable initial bulgings, which, in comparison with the thickness of the wall, may no longer be regarded as small, considerably reduce the actual buckling

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load compared with the calculated buckling load of the ideal plate or shell concerned. The experimental results are frequently somewhat scattered, so that in many cases discrimination must be exercised when drawing conclusions as to the behaviour of a structural part, based on the result of one or a few tests only. From the present report, it will be recognised that there is still much to be learned regarding the strength of plate and shell structures. In spite of many calculations, there is still a lack, in many cases, of experimental investigations on the stability of plates and shells under composite stresses, also of investigations on the stability of shells of non-circular cross-section and of variable section (for example, conical shells). In view of the very special requirements in aeroplane construction it is particularly important to obtain elucidation on many questions relative to the strength of stiffened plates and shells (wing and fuselage constructions).

Steps towards the solution of these problems have been made by the D.V.L. Experiments have been carried out on stiffened cylindrical partial shells as elements of shell fuselages and on stiffened cylindrical solid shells (shell fuselage models), the results of which hitherto obtained have still to be reported. In addition, the behaviour of cylinder shells with elliptical section under bending have been studied both mathematically and experimentally.

Symbols.

E modulus of elasticity.
G modulus of shear.
ν Poisson number (for steel and duralumin approx. 0.3).
δ wall thickness of the plate or shell.
a, b sides of a rectangular plate.
r radius of curvature of a shell.
l length of a shell.

II. Strength of Rectangular Plates.

1. *Isotropic Plates.*—(*a*) *Pressure Stress.*—To begin with, the formulæ are given for the determination of the critical stresses for a few important special cases of rectangular plates under pressure stress (Ref. 15, 16, 22, 23, 24, 26).

(i) *Constant Pressure Load on Two Opposite Sides of the Plate.*—Let a denote the unloaded sides of the plate, b the loaded sides (Fig. 1), δ the wall thickness of the plate.

The critical pressure stress σ_{kr} of the plate is obtained from the formula (1)

$$\sigma_{kr} = k \{ E/(1-\nu^2) \} (\delta/b)^2 \quad . \quad . \quad . \quad . \quad (1)$$

The coefficient k in equation (1) is a function of the aspect ratio a/b and of the boundary conditions of the plate. It is given for various boundary conditions.

1. All sides of the plate supported:—*

$a/b =$	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2
$k =$	6.92	4.23	3.45	3.29	3.40	3.68	3.45	3.32	3.29	3.32
$a/b =$	2.4	2.7	3	∞						
$k =$	3.40	3.32	3.29	3.29						

2. All sides of the plate fixed:—†

$a/b =$	1	2	3	∞
$k =$	7.7	6.7	6.4	6.0

3. Sides (a) fixed, sides (b) supported:—

$a/b =$	0.4	0.5	0.6	0.7	0.8	1.0	1.2	1.4	1.6	1.8	2.1	∞
$k =$	7.76	6.32	5.80	5.76	6.0	6.32	5.80	5.76	6.0	5.8	5.76	5.73

* "Supported here and hereafter is defined as resting without fixation."

† The limiting value of k with $a/b = \infty$ would have to agree actually for case 2 and 3. The value $k = 5.73$ is the more accurate.

(ii) *Linearly Variable Load (Perpendicular to the Edge of Plate) on Two Opposite Sides of the Plate.*—All sides of the plate are supported. Let the load of the plate be given by

$$\sigma = \sigma_o (1 - y/ab) \text{ with } \alpha = \sigma_o/(\sigma_o - \sigma_u)$$

(Fig. 2). The critical load is then obtained from

$$\sigma_{okr} = k \{ E/(1-\nu^2) \} (\delta/b)^2 \quad . \quad . \quad . \quad . \quad (2)$$

	$a/b =$	0.4	0.5	0.6	0.667	0.75	0.8	0.9	1.0	1.5
$\alpha = 0.5$;	$k =$	23.9	21.1	19.8	19.7	19.8	20.1	21.1	21.1	19.8
0.75;		15.4		10.6		9.5	9.2		9.1	9.5
1.0;		12.4		8.0		6.9	6.7		6.4	6.9
1.25;		10.95		6.8		5.8	5.7		5.4	5.8
1.50;		8.9		5.8		5.0	4.9		4.8	5.0

(iii) *Constant Pressure Load on all Sides of the Plate.*—Sides b of the plate are under the pressure load σ_1, sides a under the pressure load σ_2 (Fig. 3). If all sides of the plate are supported, pairs of critical values of σ_1 and σ_2 are obtained from the equation

$$\sigma_{1kr} (m^2/a^2) + \sigma_{2kr} (n^2/b^2) = 0.823 \{ E/(1-\nu^2) \} \delta^2 (m^2/a^2 + n^2/b^2)^2 \quad . \quad (3)$$

Here m and n denote the number of the half waves of the buckled plate in the x-direction (parallel to the sides a) and in the y-direction (parallel to the sides b); m and n are whole numbers, and should be so selected that σ_{1kr} and σ_{2kr} are as small as possible.

In the special case, $\sigma_1 = \sigma_2 = \sigma$ the critical load is determined from

$$\sigma_{kr} = k \{ E/(1-\nu^2) \} (\delta/b)^2 \quad . \quad . \quad . \quad . \quad (4)$$

in which the coefficient k depends on the boundary conditions and the aspect ratio a/b of the plate.

1. All sides of the plate supported:—

$a/b =$	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
$k =$	83.1	21.4	9.96	5.96	4.11	3.11	2.50	2.11	1.84	1.645

2. All sides of the plate fixed (Ref. 15):—

$$a/b = 1, \quad k = 4.36.$$

According to Cox (Ref. 16, 26) the values calculated for the buckling stresses of plates under pressure load, with the boundary conditions under which they were experimentally checked, are in relatively good agreement with the experimental results.

Behaviour after Buckling.—Plates under pressure, in many cases, are capable, after buckling, of supporting considerable additional loads before they actually break. In the case of a plate, the sides of which are supported or fixed, and in which two opposite sides are under pressure load, the distribution of stress over the cross-section after exceeding the buckling load is no longer uniform, but an increase of stress takes place towards the sides. The supporting capacity of the plate is exhausted when the maximum values of the pressure stress reach the yield point of the material, or when the plate, which is riveted to the unloaded sides with stiffeners, bulges out between the rivets, or again, when in the lateral stiffeners of the plate, which are compressed simultaneously with the plate, the pressure stresses have reached the critical values. The breaking load P_B of a plate under pressure load is determined from the supporting width $2w$ as

$$P_B = 2w\delta\sigma \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

in which, according to yield point of the material, σ denotes the stress under which the plate buckles between two rivets at the side fixture, or the buckling stress of the lateral stiffeners themselves, for the stressed width $2w$, with supported edges, Kármán gives (Ref. 13, 25) the formula

$$2w = C\delta\sqrt{(E/\sigma)} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

in which σ has the same meaning as in equation (5) and for constant C, the value $C=\pi/\sqrt{\{3(1-\nu^2)\}}=1.90$ with $\nu=0.3$. For steel with a yield point of 30 kgm.$^{-2}$ the stressed width $2w$ becomes approx. 50δ and for duralumin with a yield point of 27 kgm.$^{-2}$ becomes $2w\approx 30\delta$, the yield point of the material being considered as the decisive factor for breaking.

If the plate is free on one unloaded side and supported on the three remaining sides, v. Kármán calculates the value

$$w=0.68\,\delta\sqrt{(E/\sigma)} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

for the stressed width.

Cox (Ref. 16, 26) obtains the formula

$$2w=C\delta\sqrt{(E/\sigma)}+Db \quad . \quad . \quad . \quad . \quad . \quad (8)$$

for the stressed width $2w$, *i.e.*, this width varies slightly also with width b of the plate, C and D are constants depending on the boundary conditions of the plate.

All sides of the plate supported:—$C=1.50$, $D=0.09$.

The loaded sides of the plate are supported, the unloaded sides fixed:—$C=2.16$, $D=0.14$.

Available experimental results (Ref. 16, 17) are in moderately good agreement with the formula (8) according to the estimations of Cox. Reference may be made also to papers by Schnadel (Ref. 9, 10, 11) which likewise relate to the behaviour of plates under pressure stresses after exceeding the limit of stability.

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(*b*) *Shearing Stress.*—The critical shearing stress τ_{kr} of a rectangular plate of the sides a and b and wall thickness δ under shear is obtained from the formula

$$\tau_{kr} = k \{ E/(1-\nu^2) \} (\delta/b)^2 \quad . \quad . \quad . \quad . \quad (9)$$

The coefficient k in equation (9) depends on the boundary conditions and the aspect ratio a/b of the plate.

1. All sides of the plate supported (Ref. 11, 12, 13):—

$a/b =$	1.0	1.2	1.4	1.5	1.6	1.8	2.0	2.5	3.0	∞
$k =$	7.75	6.58	6.0	5.84	5.76	5.59	5.43	5.18	5.02	4.4

2. All sides of the plate fixed (Ref. 14):—

$a/b =$	1	2	∞
$k =$	12.7	9.5	7.4

Cox (26) notes that for approximately square plates the results of experiments are in fairly good agreement with calculations, but that for plates of aspect ratio a/b, differing greatly from unity, may buckle long before attaining the mathematically determined critical load. Seydel (8) refers to the highly disturbing influence of initial bulging in the case of thin plates. Bollenrath (Ref. 6) states that in his experiments on celluloid plates, the experimental values for the critical shear are obtained mathematically at about 43 per cent. below those calculated by Southwell and Skan (Ref. 2).

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(*c*) *Composite Stresses.*—In the case of a long rectangular plate stressed simultaneously under uniform pressure or tension (σ_x, σ_y) and shear τ (Fig. 4) Wagner has derived two formulæ for the calculation of the critical shear τ_{kr} (Ref. 1) with given $\sigma_x y \sigma_y$ with supported edge:—

$$\tau^2_{kr} = H^2 \{ 2\sqrt{(\sigma_y/H + 1)} + 2 + \sigma_x/H \} \{ 2\sqrt{(\sigma_y + 1)} + 6 + \sigma_x/H \} \quad . \qquad (10)$$

With fixed edge:—

$$\tau^2_{kr} = H^2 \{ (4/\sqrt{3})\sqrt{(\sigma_y/H + 4)} + 8/3 + \sigma_x/H \} \{ (4/\sqrt{3})\sqrt{(\sigma_y/H + 4)} + 8 + \sigma_x/H \}$$
$$H = (\pi^2/12) \{ E/(1 - \nu^2) \} (\delta/b)^2 \quad . \quad . \quad . \quad . \qquad (11)$$

Wagner also represents equations (10) and (11) graphically, by plotting curves τ_{kr} = constant in the σ_x, σ_y field.

The rectangular plate (Fig. 5) stressed simultaneously under bending and shear has been dealt with in a paper by Stein (Ref. 2) with regard to its stability.

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Dealing with the strength of isotropic plates under compound loading.

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2. *Orthotropic Plates.*—A stiffened plate, in many cases, if the stiffeners lie at sufficiently close intervals, may be regarded as an orthotropic plate, *i.e.*, a plate with variable stiffness in two directions perpendicular to each other. This applies especially when dealing with the stability of corrugated sheet.

(*a*) *Pressure Stress.*—According to Dean (Ref. 1, 5) the formula

$$\sigma_{kr} = k \{ E/(1 - \nu^2) \} (\delta/a)^2 \quad . \quad . \quad . \quad . \qquad (12)$$

holds for the critical pressure stress σ_{kr} of a corrugated metal plate with sides a and b (a parallel to the generatrix) which is uniformly loaded on the sides b under pressure (Fig. 1).

If s denotes the length of chord of a half corrugation of the plate, and f the depth of the corrugation (distance of a peak from the middle plane) and if $s/a < 0.2$ we may put approximately

$$k = 5.8 (f^2/\delta^2) \quad . \quad . \quad . \quad . \quad . \qquad (13)$$

The buckling stress σ_{kr} is thus independent of the thickness δ of the sheet. Probably k varies also with the half length of corrugation λ, though this is not expressed in formula (13).

Yamana (Ref. 3) gives the formula

$$\text{if } a/b > \sqrt{(D_1/D_2)}: \; s_{kr} = 2 (\pi^2/b^2) (\sqrt{D_1 D_2} + D_3) \quad . \quad . \quad . \qquad (14)$$
$$\text{if } a/b < \sqrt{(D_1/D_2)}: \; s_{kr} = (\pi^2/b^2) [(b/a)^2 D_1 + (a/b)^2 D_2 + 2 D_3]$$

for the critical pressure load s_{kr} (referring to the unit length of the edge) of an orthotropic plate with edges supported. D_1 and D_2 are the stiffnesses against

bending of the orthotropic plate, D_3 is a function of D_1 and D_2 and of the torsional stiffness of the plate. The calculation of these quantities is given later.

Formula (14) is in harmony with a formula given by Wagner (Ref. 2) for the stability of a stiffened plate under pressure.

If the unloaded sides of the orthotropic plate are fixed, the critical pressure load s_{kr} is calculated from

$$s_{kr} = 2\,(\pi^2/b^2)\,\{\,2\,D_1\,(b^2/a^2) + D_3\,\} \quad . \quad . \quad . \quad (15)$$

in which, however, D_2 is assumed to be small in relation to D_1.

For the results of the American experiments on corrugated sheet metal see Ref. 2.

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Dealing with the strength of orthotropic rectangular plates under pressure.

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(*b*) *Shearing Stress.*—For the calculation of the critical shearing load t_{kr} (with reference to unit length of the edge of the plate) of an orthogonal-anisotropic (orthotropic) rectangular plate (Fig. 6) with sides a (in the direction of the x-axis) and b (in the direction of the y-axis) stiffness against bending D_1 in the x-direction (*i.e.*, bending about the y-axis) and bending resistance D_2 in the y-direction (bending about the x-axis), the following formula may be applied (Ref. 8):—

$$t_{kr} = c_a\,(D_1 D_2^3)^{\frac{1}{4}}/(b/2)^2 \quad . \quad . \quad . \quad . \quad (16)$$

where c_a is a coefficient depending on the two parameters

$$\theta = (D_1 D_2)^{\frac{1}{2}}/D_3 \text{ and } \beta_a = (b/a)/(D_1/D_2)^{\frac{1}{4}}$$

and according to Seydel, may be taken from diagram Fig. 7 for θ values from 1 to ∞ and for β_a values from 0 to 1. The c_a values of the diagram Fig. 7 hold for the case where all sides of the plate are supported. The quantity D_3 is a function of the bending stiffnesses D_1, D_2 and the torsional stiffness of the plate. The formulæ for the calculation of D_1, D_2 and D_3 are given later.

With orthotropic plates, very long in relation to the width b (infinite length), and θ values between 1 and ∞, the critical shearing load t_{kr} for supported and fixed edges may be determined from formula (16), c_a being obtained from the following table (Ref. 4):—

	$\theta =$ 1	2	3	5	10	20
Edges supported:	$c_a = 13.17$	10.8	9.95	9.25	8.7	8.4
,, fixed:	$c_a = 22.15$	18.75	17.55	16.6	15.85	15.45
	$\theta = 40$	∞				
Edges supported:	$c_a = 8.25$	8.125				
,, fixed:	$c_a = 15.25$	15.07				

If the θ values of the orthotropic plates of infinite length lie between 0 and 1, the critical shearing load t_{kr} is calculated from formula

$$t_{kr} = c_b\,(D_2 D_3)^{\frac{1}{4}}/(b/2)^2 \quad . \quad . \quad . \quad . \quad (17)$$

c_b being obtained from the following table:—

	$\theta =$ 0	0.2	0.5	1.0
Edges supported:	$c_a = 11.71$	11.8	12.2	13.17
,, fixed:	$c_a = 18.59$	18.85	19.9	22.15

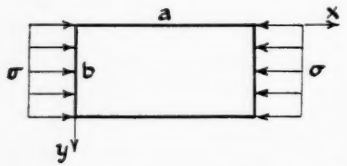


FIG. 1.
Rectangular plate with two edges under constant pressure load.

FIG. 2.
Rectangular plate with two edges under pressure and bending stresses simultaneously.

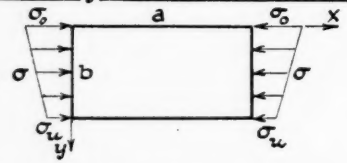
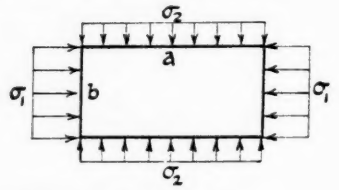
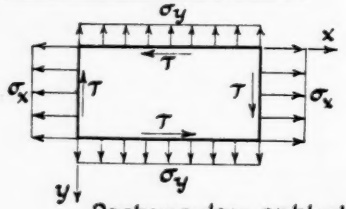


FIG. 3.
Rectangular plate, with all sides under pressure.



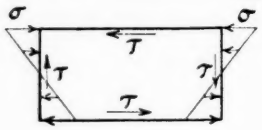
Rectangular plate with composite pressure and shearing stresses.

FIG. 4.



Rectangular plate with composite bending and shearing stress.

FIG. 5.



Rectangular orthotropic plate under shearing stress.

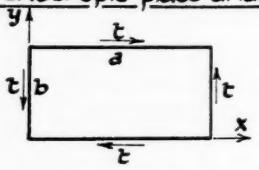


FIG. 6.

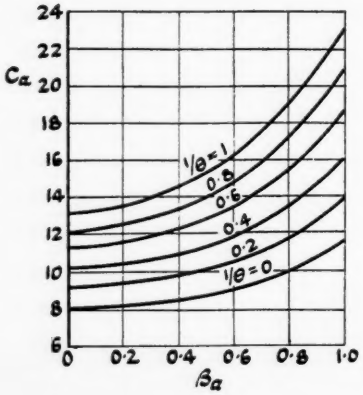


FIG. 7.
Coefficients c_a as a function of β_a and $1/\theta$.

FIG. 8.

Rectangular plate of corrugated sheet metal.

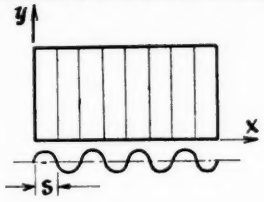
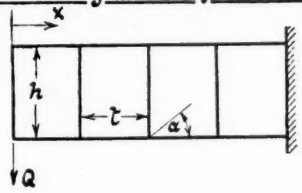


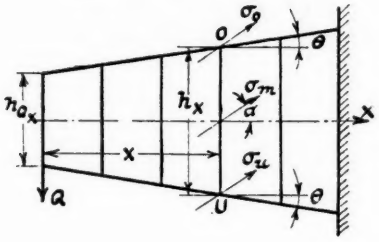
FIG. 9.

Sheet metal girder with parallel flanges. (Longitudinals).



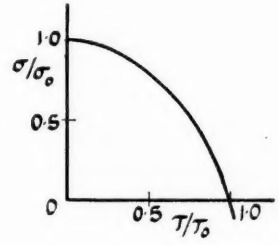
Sheet metal girder with non parallel longitudinals.

FIG. 10.



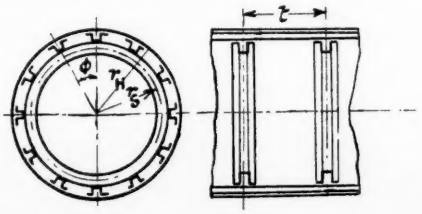
Values of σ/σ_o as a function of τ/τ_o.

FIG. 11.



Circular cylinder shell (with longitudinal and transverse stiffness).

FIG. 12.



The length l_{kr} of a half corrugation of the buckled plate in the x-direction is obtained from the formulæ

$$l_{kr} = c_a' (b/2) (D_1/D_2)^{\frac{1}{4}} \text{ for } \theta \geqq 1 \quad . \quad . \quad . \quad (18)$$

$$l_{kr} = c_b' (b/2) (D_3/D_2)^{\frac{1}{2}} \text{ for } \theta \leqq 1 \quad . \quad . \quad . \quad (19)$$

The coefficients c_a' and c_b' may be obtained from the following table:—

		$\theta = 1$	2	3	5	10	30
Edges	supported:	$c_a' = 2.49$	2.28	2.16	2.13	2.08	2.05
,,	fixed:	$c_a' = 1.66$	1.54	1.48	1.44	1.41	1.38
		$\theta = 0.05$	0.2	0.5	1		
Edges	supported:	$c_b' = 1.92$	1.94	2.07	2.49		
,,	fixed:	$c_b' = 1.16$	1.20	1.36	1.66		

Knowledge of the length of the half corrugation is important for the determination of the question, whether a plate with periodically variable stiffnesses in two directions perpendicular to each other (parallel to the edges of the plate) may be considered as orthotropic plate. Only when the half length of the corrugation l_{kr} is a multiple of the distance between the stiffeners of the plate or of the ridges of the corrugated sheet, may the plate be treated approximately as an orthotropic plate with regard to its critical behaviour.

Formulæ for the calculation of the quantities D_1, D_2, D_3 (Ref. 4):—

$$D_1 = (EJ)_x/(1 - \nu_x \nu_y) \quad . \quad . \quad . \quad . \quad . \quad (20)$$

$$D_2 = (EJ)_y/(1 - \nu_x \nu_y) \quad . \quad . \quad . \quad . \quad . \quad (21)$$

$$D_3 = \tfrac{1}{2} (\nu_x D_2 + \nu_y D_1) + 2 (GJ)_{xy}$$

D_1 is the stiffness against bending of the plate in x-direction (*i.e.*, about the y-axis).

D_2 is the stiffness against bending of the plate in the y-direction (*i.e.*, about the x-axis).

$4 (GJ)_{xy}$ is the stiffness against torsion of the orthotropic plate, ν_x, ν_y are the Poisson numbers, corresponding to the bending stresses in the x and y directions respectively of the plate.*

The relation

$$\nu_y D_1 = \nu_x D_2$$

holds, with which D_3 becomes

$$D_3 = \nu_y D_1 + 2 (GJ)_{xy} = \nu_x D_2 + 2 (GJ)_{xy} \quad . \quad . \quad . \quad (22)$$

For corrugated sheet, in which the corrugations are parallel to the y-direction (Fig. 8)

$$D_1 = (l/s) (E\delta^3/12) \{ 1/(1 - \nu^2) \}$$

l = length of arc of a half corrugation.
s = length of chord of a half corrugation,

$$D_2 = EJ$$

where J is the mean moment of inertia per unit length of the corrugated sheet cross-section parallel to x-axis, relative to the axis in the central plane of the plate, and

$$D_3 = (l/s) (G\delta^3/6)$$

neglecting $\nu_y D_1$. For further details see Ref. 7.

The results of experiments on corrugated plates, loaded under shear, are in good agreement with calculations (Ref. 7).

A simple formula for the estimation of the critical shear load of a stiffened orthotropic plate has already been given by Wagner (Ref. 5).

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* With reference to the determination of ν_x, ν_y, see Ref. 8.

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3. *Plates with Stiffeners.*—With regard to the strength of stiffened plates it is important to know the limit of stability of the stiffened plate under pressure and/or shearing load. In most cases, however, the supporting capacity of the stiffened plate is not exhausted on reaching the limit of stability, but the load may still be considerably increased before reaching breaking point.

(*a*) *Pressure Stress.*—For the investigation of the stability of a stiffened plate, in many cases, if the stiffeners lie sufficiently close together, the plate may be regarded as orthotropic, and the formulæ given in Chapter II, 2, applied. In order to determine the buckling load of a field of the sheet between more widely separated stiffeners, formula (1) may be used, in which, however, the bending deformation of the stiffeners is assumed to be so small that the sides of the field of the sheet may be regarded as straight. The influence of the flexibility to bending of the stiffeners on the stability of the fields between the stiffeners has been dealt with in a paper by Timoschenko (Ref. 1). The critical pressure stress of the stiffened sheet likewise is determined from formula (1); the coefficient k, however, depends not only on the boundary conditions of the plate and its aspect ratio a/b, but also on the number of stiffeners, the ratio of the bending stiffnesses of the stiffeners and of the sheet and the ratio of the cross-sectional areas on the stiffeners and of the sheet. Timoschenko has calculated and tabulated the coefficient k for a number of cases (Refs. 1, 7, 8).

For aeroplane construction, knowledge of the breaking load is the most important, *i.e.*, of the supporting capacity of a plate with longitudinal stiffeners, stressed under pressure parallel to the stiffeners. Three methods have been suggested for the approximate estimation of the breaking load (Ref. 3).

1. The breaking load of the stiffeners alone and that of the sheet between two stiffeners are determined (by calculation or experiment), the lateral edges of the sheet being considered as rigidly supported, and the breaking load of the sheet and stiffeners added, in order to obtain the breaking load of the stiffened plate (Ref. 5).

2. The breaking load of a stiffener is determined (by experiment) and the stressed width $2w$ or w of the sheet calculated from the breaking stress of the stiffener according to formulæ (6) and (7). The total area of the stiffeners and the stressed skin multiplied by the breaking stress σ gives the breaking load of the stiffened plate.

From the experiments by Schuman and Back (Ref. 4), Lundquist (Ref. 3) deduces that in equation (6) and (7) of Chapter II, 1, it is better to calculate

with 1.70 and 0.60 instead of coefficients 1.90 and 0.68, so that the following formulæ are obtained for the stressed width of the plate of a stiffened structure.

For the stressed width of the sheet between two stiffeners

$$2w = 1.70\,\delta\sqrt{(E/\sigma)} \quad . \quad . \quad . \quad . \quad . \quad (23)$$

for that of the sheet projecting free beyond the stiffening on one side of the stiffened plate

$$w = 0.60\,\delta\sqrt{(E/\sigma)} \quad . \quad . \quad . \quad . \quad . \quad (24)$$

3. The breaking stress σ of the stiffeners alone is plotted as a function of the fineness ratio. With an estimated breaking stress the stressed width of the skin is calculated from formulæ (23) and (24). The fineness ratio of the combination, stiffening plus stressed skin, is then determined, and from the original curve which actually applies only to the profile alone, the appropriate breaking stress σ is determined. If this breaking stress is not in agreement with the value assumed the procedure is repeated. Usually two or three repetitions will suffice. From the final breaking stress and the cross-section of the stiffeners and stressed skin, the breaking load of the stiffened plate is determined.

As American experiments show (Ref. 3), this last method is best suited for the calculation of the breaking load of a stiffened shell. It should be noted, further, that in making buckling tests on the stiffeners alone, care must be taken that the profiles buckle as nearly as possible, as they do when in conjunction with the skin, *i.e.*, at right angles to the skin.

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(*b*) *Shearing Stress.*—The stability and strength of a stiffened plate under shear has been dealt with in detail by Wagner (Ref. 1, 2), the thin sheet metal skin being assumed as becoming bulged under very small loads. Apart from the bending stresses due to creasing, a monaxial state of stress, a " field of tension diagonals " is set up in the skin. The characteristics of this field have also been described in detail by Wagner.

The simple methods of calculation by Wagner in which the boundary bars* are assumed as being so stiff that they may be considered as rigid with respect to bending are given below for two important practical cases. This assumption is entirely permissible for many practical cases. With regard to the considera-

* *i.e.*, longitudinals (flanges) and end verticals.

tion of the influence of the flexibility to bending of the stiffeners, reference should be made to Wagner's papers (Ref. 2).

1. *Sheet Metal Girder with Parallel Flanges and Vertical (Web) Bars.*—A sheet metal girder with parallel flanges (distance between flanges h) and vertical (web) bars (width apart t) is fixed at one end and loaded at the other end by the force Q (Fig. 9). If the boundary bars are rigid against bending, the tensile stress σ in the sheet and the direction of crease α are invariable. With δ as the thickness of the sheet the tensile stress in the sheet will be

$$\sigma = (2\,Q/h\delta)\,(1/\sin 2\,\alpha) \quad . \quad . \quad . \quad . \quad (25)$$

the pressure in a vertical bar is

$$-V = Q\,(t/h)\,tg\alpha \quad . \quad . \quad . \quad . \quad . \quad (26)$$

the forces in the top and bottom flanges respectively

$$H_o = (Q\,.\,x/h) - (Q/2)\cot\alpha, \quad H_u = -(Q\,.\,x/h) - (Q/2)\cot\alpha \qquad (27,\ 28)$$

x is the distance of the cross-section in which the forces H_o and H_u in the flanges are to be determined from the force Q.

The maximum local bending moment in the flanges (at the connecting points of the vertical bars) will be

$$B_{H\max} = (Q/h)\,(t^2/12)\,tg\alpha \quad . \quad . \quad . \quad . \quad (29)$$

The direction of buckling α is calculated from

$$\sin^2\alpha = +\sqrt{(a^2+a)} - a \text{ with } a = (1 + h\delta/2\,F_H)/(t\delta/F_v - h\delta/2\,F_H) \quad (30,\ 31)$$

(F_H, F_v = cross-section of the flanges and vertical bars.) It is sufficient, however, in most technical calculations to estimate $\alpha = 40°$ to $42°$ and to calculate with the formulæ

$$\sigma = 2\,Q/h\delta \quad . \quad . \quad . \quad . \quad . \quad (32)$$

$$-V = 0.9\,Q\,(t/h) \quad . \quad . \quad . \quad . \quad . \quad (33)$$

$$H_{o,\,u} = \pm Q\,.\,x/h - 0.6\,Q \quad . \quad . \quad . \quad . \quad (34)$$

Wagner proves that the influence of the fixing of the sheet metal at the flanges or verticals, in which the buckling of the sheet is restricted to one plane, is negligibly small in the case of very thin sheet metal.

2. *Sheet Metal Girder with Non-parallel Rigid Flanges.*—With straight flanges, inclined at an angle θ or $-\theta$ to the axis of the girder (Fig. 10), assuming constant transverse force Q and constant direction of buckling α in a cross-section at a distance approximately x from the load Q, the tensile stress in the sheet at the centre of the girder is

$$\sigma_m = (Q/\delta)\,(h_{Qx}/h_x^2)\,(1/\sin\alpha\cos\alpha) \quad . \quad . \quad . \quad (35)$$

and in the sheet on the top and bottom flanges respectively

$$\sigma_o = \sigma_m\,\{\,1/(1 - \cot\alpha\, tg\theta)^2\,\}\,, \quad \sigma_u = \sigma_m\,\{\,1/(1 + \cot\alpha\, tg\theta)^2\,\} \qquad (36,\ 37)$$

With reference to the symbols h_x and h_{Qx}, see Fig. 11. The pressure in a vertical bar will be

$$-V = Q\,(t/h_x)\,tg\alpha \quad . \quad . \quad . \quad . \quad . \quad (38)$$

These formulæ, however, are only approximate.

In the case of a sheet metal girder in which the vertical bars are eccentric to the web plate and riveted to the latter, the bars are uniformly stressed under eccentric pressure over their whole length.

Contrary to usual bars under eccentric pressure, eccentric bars of a sheet metal girder connected with the web plate also have a real buckling load (Problem of Stability). Wagner also describes experiments with such elements (Ref. 2).

As experiments (Ref. 1, 3) have shown, Wagner's simple calculations are in good agreement with the actual conditions.

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Relative to the strength of rectangular plates with stiffeners under stress.

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III. Strength of Circular Cylindrical Partial Shells.

1. *Isotropic Partial Shells.* (*a*) *Axial Pressure Stress.*—Redshaw has worked out the following mathematical formula for the critical pressure stress of an isotropic cylindrical partial shell under axial pressure:—

$$\sigma_{kr} = \left(\tfrac{1}{6}\right) \{ E/(1-\nu^2) \} \{ \sqrt{[12\,(1-\nu^2)\,(\delta/r)^2 + (\pi\delta/b)^4]} + (\pi\delta/b)^2 \} \qquad (39)$$

in which δ = the wall thickness of the partial shell.

r = radius of curvature of the partial shell.

b = length of curve of the cross-section central area of the shell.

The edges of the shell are assumed as being supported. Formula (39), in the case where $(\delta/b)^2$ is negligibly small in relation to δ/r is transformed into formula (41) for the buckling stress of the circular cylindrical solid shell under axial pressure. If, on the contrary, δ/r is small in relation to $(\delta/b)^2$, relation (1) is obtained from formula (39) for the critical pressure stress of a plate supported on all sides and under pressure load on two opposite sides of length b.

According to Redshaw (Ref. 1) formula (39) is also corroborated by experiment; nevertheless, further experiments appear desirable in this direction.

References

Relative to the strength of isotropic circular cylindrical partial shells under axial pressure.

1. S. C. Redshaw. The elastic instability of a thin curved panel. Aeron. Res. Comm. Rep. and Mem. 1565, London 1934. T.
2. H. L. Cox. Summary of the present state of knowledge regarding sheet metal construction. Aeron. Res. Comm. Rep. and Mem. 1553, London 1933. Z.
3. H. J. Pollard. Some developments in aircraft construction. J. Roy. Aeron. Soc. Bd.38 (1934), S.651/686. Z.

(*b*) *Shearing Stress.*—For the critical shear τ_{kr} of cylindrical partial shells without stiffeners under shear, Wagner (Ref. 1) gives the formulæ

$$\tau_{kr} = k_s E\,(\delta/r) + 5\,E\,(\delta/b)^2$$

for supported plates, and

$$\tau_{kr} = k_s E\,(\delta/r) + 7{\cdot}5\,E\,(\delta/b)^2$$

for fixed plates in which b is the length of curve of the curved sides of the partial shell and $k_s \approx 0.3$.* From experiments on partial shells with quadrantal section Smith (Ref. 2) obtains

$$\tau_{kr} = kE\,(\delta/r) \qquad . \quad . \quad . \quad . \quad . \qquad (40)$$

* According to recent experiments by Wagner $k_s \approx 0.1$.

with $k=0.075$; the wall thicknesses δ of the experimental pieces were between 0.25 mm. and 0.81 mm. and the radius r between 11 cm. and 18 cm.

For the shear under which breaking takes place, according to Smith the formula (40) may also be used, putting the coefficient $k=0.20$. The experimental values for the breaking loads, however, are somewhat scattered.

References

Relative to the strength of isotropic cylindrical partial shells under shear.

1. H. Wagner. Über Konstruktions- und Berechnungs-fragen des Blechbaues. Jb. wiss. Ges. Luftf. (1928). S.113/125. TV.
2. G. M. Smith. Strength in shear of thin curved sheets of alclad. N.A.C.A. Techn. Note 343, Washington 1930. V.

2. *Partial Shells with Stiffeners.—Axial Pressure Stress.**—According to Lundquist (Ref. 1) the supporting capacity of a cylindrical partial shell, stiffened longitudinally, and under pressure stress, may be calculated in the same way as for a stiffened plate (Chapter II, 3). As before, the last of the three methods given is best suited for the determination of the strength. It has been found by experiment, however (Ref. 2), that the supporting capacity of a stiffened cylindrical partial shell with high r/δ values (approximately 1,000) is less than that of a stiffened flat plate. Lundquist recommends, therefore, that a deduction of 10 to 15 per cent. be made from the strength calculated by the third method.

References

Relating to the strength of stiffened cylindrical partial shells under pressure.

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IV. Strength of Circular Cylindrical Solid Shells.

1. *Isotropic Solid Shells.* (*a*) *Axial Compression Stress.*—Stability failure in a circular cylindrical shell without stiffeners under axial pressure may occur, according to the length of the shell:—

1. By buckling of the side of the shell as a whole (Euler's case).
2. By local buckling (bulging out) of the cylinder wall.

Local buckling consists either in the form of annular swellings, when all the lines of the envelope deform in the same way in the form of undulations and the shell cross-sections remain circular (buckling symmetrical about the axis), or in the form of actual bulges, when the shell cross-sections also assume an undulatory form. For both cases the formula

$$\sigma_{kr}=(1/\sqrt{3})\{E/\sqrt{(1-\nu^2)}\}(\delta/r) \quad . \quad . \quad . \quad (41)$$

has been derived for the calculation of the buckling stress of the cylinder shell.† Relation (41) applies, strictly speaking, to the shell of infinite length only. The influence of the length of the shell, however, almost completely disappears when the length is a few times half the length of the bulge undulation in the axial

* See also the paper by Dschou in Luftfahrtforschung No. 8, 6.11.35.

† Frequently also a formula of Southwell's for σ_{kr} is to be found in the References 4, 5, 14, 17, in which the factor $(k^2-1)/(k^2+1)$ (k=number of waves round the periphery) appears and which is applicable in the case of bulging which is not symmetrical about its axis. This formula, however, has been objected to by Robertson (Ref. 10), v. Sanden and Tölke (Ref. 8) and has now ceased to be employed in recent British formulæ.

direction. The half length of the undulation calculated in the case of buckling of the shell symmetrical about its axis is

$$\lambda/2 = 1.72\sqrt{r\delta} \quad . \quad . \quad . \quad . \quad . \quad (42)$$

Formulæ (41) and (42) are based on the assumption of the validity of Hooke's law. If σ_{kr} exceeds the limit of proportionality of the material, it is replaced by the formulæ

$$\sigma_{kr} = (1/\sqrt{3})\,(\delta/r)\sqrt{\{EK/(1-\nu^2)\}} \quad . \quad . \quad . \quad (43)$$

$$\lambda/2 = 1.72\sqrt{r\delta}\,(K/E)^{\frac{1}{4}} \quad . \quad . \quad . \quad . \quad (44)$$

(Ref. 7) where the " buckling modulus " K may be calculated from

$$K = 4EE'/(\sqrt{E}+\sqrt{E'})^2 \quad . \quad . \quad . \quad . \quad (45)$$

In formula (45) $E' = d\sigma/d\xi$ is to be determined in the place of $\sigma = \sigma_{kr}$ from the stress strain diagram of the material.

Experiments as a check on formula (41) have been carried out at different times. They have consistently shown lower values than those corresponding to those calculated by this formula, viz., most experimental values for the buckling stress lie at about 40 to 60 per cent. of the mathematical values.

In explanation of this fact, two circumstances have been considered which reduce the breaking load and are not taken into account in the development of the mathematical formula.

1. In the test pieces there are always more or less marked departures from the true circular cylindrical form (Refs. 9, 10).

2. Owing to the transverse extension of the compressed shell which is prevented at the ends of the cylinder by the fixing or by the friction on the pressure plates, a local bending deformation of the cylinder (wall) takes place, which likewise may cause a reduction of the breaking load (Refs. 6, 7, 8, 9).

Reference has frequently been made to the analogy of the problem of stability of the cylinder shell under axial compression with that of the buckling of an elastically embedded bar (Ref. 13).

References

Relating to the strength of isotropic cylindrical solid shells under axial compression.

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(*b*) *Bending Stress.*—The following formula was derived for the bending moment B_{kr}, under which the stability fracture of a thin-walled circular cylindrical shell under bending stress occurs (Refs. 1, 2):—

$$B_{kr} = k \{ E/(1-\nu^2)^{\frac{1}{2}} \} r\delta^2 \quad . \quad . \quad . \quad . \quad (46)$$

For the coefficient k Brazier gives the value $k=0.99$. The mean value for k, obtained from 77 experiments on this question, is $k_{mean}=1.14$, the minimum value of k in these experiments was 0.72. Brazier's theory first holds only for the case of pure bending, and with great length of cylinder shell. Experiments hitherto have shown, however, that apart from very short shells, the influence of the cylinder length is negligible (Ref. 4). Likewise no sensible reduction of the critical bending moment due to a small transverse force has been determined (Ref. 3).

References

Relative to the strength of isotropic cylindrical solid shells under bending.

1. L. G. Brazier. The flexure of thin cylindrical shells and other "thin" sections. Aeron. Res. Comm. Rep. and Mem. 1081, London 1927 und Proc. Roy. Soc. Lond. Ser. A Bd.116 (1927). S.104/114. TV.
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5. J. E. Younger. Principle of similitude as applied to research on thin-sheet structures. Aeron. Engng. Bd.5 (1933), Heft 4, S.163/169. V.
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(*c*) *Torsional Stress.*—A circular cylinder shell which is twisted by torsional moments introduced on the ends may be caused to break, if the walls are of sufficiently small thickness, by local bulging of the cylinder wall. The following formulæ have been derived by Donnell for the calculations of the critical shearing stress τ_{kr} in the case of fixed or supported edges (Ref. 5).

Calculated critical shearing stresses. Edges fixed:—

$$\tau_{kr} = \{ E/(1-\nu^2) \} (\delta/l)^2 [4.6 + \sqrt{(7.8 + 0.590\, H^{3/2})}] \quad . \quad (47)$$

Edges supported:—

$$\tau_{kr} = \{ E/(1-\nu^2) \} (\delta/l)^2 [2.8 + \sqrt{(2.6 + 0.494\, H^{3/2})}] \quad . \quad (48)$$
$$H = (l^2/\delta r)\sqrt{(1-\nu^2)}$$

in which l is the length, r the radius, and δ the wall thickness of the cylinder shell.

Formulæ (47) and (48) only hold when the inequalities

$$l/r > 7.9 (1-\nu^2)^{\frac{1}{4}} \sqrt{(r/\delta)} \text{ (edges fixed)} \quad . \quad . \quad . \quad (49)$$
$$l/r < 6.6 (1-\nu^2)^{\frac{1}{4}} \sqrt{(r/\delta)} \text{ (edges supported)} \quad . \quad . \quad (50)$$

are satisfied. In other cases (*i.e.*, with very long cylinder shells) the formula

$$\tau_{kr} = 0.272 \{ E/(1-\nu^2)^{3/4} \} (\delta/r)^{3/2} \quad . \quad . \quad . \quad (51)$$

should be used in the case of both fixed and supported edges. By reduction of all available experiments on this question, Donnell found that the mean critical shearing stresses found by experiment are about 75 per cent. of the calculated values. Donnell attributed this discrepancy to inaccuracies in the form of the test pieces. The lower limit of the experimental values is about 60 per cent. of the calculated values. By multiplying the right sides of (47) and (48) by 0.6 and putting $\nu = 0.3$, the following formulæ are obtained in place of (47) and (48) for calculation of the critical shearing stresses, which in practical application will always ensure being on the safe side in all normal cases.

Actual critical shearing stresses to be expected. Edges fixed:—

$$\tau_{kr} = E\,(\delta/l)^2\,[3.0 + \sqrt{\{\,3.4 + 0.240\,l^3/(\delta r)^{3/2}\,\}}\,] \quad . \quad . \quad (52)$$

Edges supported:—

$$\tau_{kr} = E\,(\delta/l)^2\,[1.8 + \sqrt{\{\,1.2 + 0.201\,l^3/(\delta r)^{3/2}\,\}}\,] \quad . \quad . \quad (53)$$

Lundquist gives a purely empirical formula for the calculation of the critical shearing stress (Ref. 6)

$$\tau_{kr} = kE\,(\delta/r)^{1.35} \quad . \quad . \quad . \quad . \quad . \quad (54)$$

Here the coefficient k depends on the ratio l/r and may be obtained from the following table:—

l/r =	0.2	0.25	0.3	0.4	0.5	0.75	1.0	1.5	2.0	3.0	4.0	5.0
k =	3.3	2.75	2.45	2.02	1.78	1.45	1.27	1.06	0.94	0.78	0.68	0.61

The first mathematical investigations of the torsional stability of the thin-walled circular cylinder shell were made by Schwerin (Ref. 1). For the shell of infinite length he obtained the formula

$$\tau_{kr} = 0.248\,E\,(1 + 0.45\,\delta/r)\,(\delta/r)^{3/2} \quad . \quad . \quad . \quad (55)$$

In addition he calculated the case of finite cylinder shells with supported edges for ratios r/δ between 25 and 50 and has represented the results graphically. Experiments, hitherto however, have been carried out only on shells with much larger r/δ values, so that a direct comparison between Schwerin's calculations and experimental results has not yet been possible. Calculation has been made by the D.V.L. applying Schwerin's theory for the case with $r/\delta = 1{,}000$ and supported shell edges. The results of this calculation are fairly consistent with 0.75 of the values calculated by Donnell's method.

Sezawa's papers (Refs. 2, 4) are important from a technical experimental point of view, but his theory, however, is inaccurate, since even in the relation for the conditions of equilibrium, an essential expression is omitted. The results calculated by this method again fail to show agreement with Sezawa's experiments.

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Relative to the strength of isotropic cylindrical solid shells under torsion.

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2. K. Sezawa und K. Kubo. The buckling of a cylindrical shell under torsion. Aeron. Res. Inst. Tokyo Univ., Report 76 (1931). TV.
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(*d*) *Composite Stresses due to Axial Compression and Torsion.*—If the critical pressure stress of an isotropic circular cylinder shell under axial compression alone is σ_0 and the critical shearing stress under torsion alone is τ_0 and the critical stresses with combined load are σ and τ, the equation

$$1-\sigma/\sigma_0=(\tau/\tau_0)^n \quad . \quad . \quad . \quad . \quad . \quad . \quad (56)$$

holds approximately, which, with known σ_0 and τ_0 renders it possible to calculate the critical stresses σ and τ under composite stresses. Equation (56) is represented graphically in Fig. 11. From experiments on circular cylinder shells, simultaneously under torsion and axial compression or tension, the value r has been found to be approximately $n=3$ (Ref. 1).

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Relating to the strength of isotropic cylindrical solid shells under composite stresses.

1. F. J. Bridget, C. C. Jerome und A. B. Vosseller. Some new experiments on buckling of thin-wall constructions. Trans. Amer. Soc. mech. Engr. Bd.**56** (1934), Heft **8**, S.**569**/**578**. V.

2. *Orthotropic Shells. Composite Stress due to Axial Compression and External Radial Pressure. Torsional Stress.*—Yamana (Ref. 1) has investigated the stability of orthotropic circular cylindrical shells under composite load consisting of axial compression, external radial pressure and torsion. The results, however, have not yet been reduced in such a form that the critical loads can be determined directly from definite formulæ.

As a check on his calculations Yamana has made experiments on cylindrical shells of corrugated sheet metal. The experiments with axial compression showed a mean value of only about 50 per cent. of the calculated critical values. One experiment only was made with pure torsional load. The difference between the experimental and the calculated values was about 12 per cent. The number of undulations n predicted from the calculation were in agreement, however, in all cases with those obtained by the experiments.

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Relating to the strength of orthotropic circular cylindrical solid shells under composite stresses.

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3. *Solid Shells with Stiffeners. Approximate Calculation in the Case of Torsion.*—A few formulæ are given below for the approximate calculation of the stresses in the skin and in the stiffeners of a stiffened circular cylindrical solid shell stressed by the torsional moment T. Fig. 12 shows the structure of the system, on which further considerations are based. On the transverse stiffeners (stays) there are longitudinal stiffeners distributed uniformly round the periphery, these in turn being riveted to the outer skin of the shell. The distance between the longitudinal stiffeners is assumed to be small.

If the outer skin is very thin it will bulge with quite a small load and produce fields of tension diagonals. Let this case alone be considered. Let the tension diagonals be inclined at the angle α to the axis of the cylinder. α may be calculated approximately by a formula given by Professor Wagner:—

$$tg^2\,\alpha=(1-\sigma_x/\sigma)/\{1-\sigma_y/\sigma+(E/\sigma)(\phi^2/24)\} \quad . \quad . \quad (57)$$

where σ = tensile stress in the skin in the direction of the tension diagonals,

σ_x = normal stress in the longitudinal stiffeners.

σ_y = normal stress in the transverse members.

ϕ = angle at the centre determined by two adjacent longitudinal stiffeners.

In formula (57) the stresses σ, σ_x and σ_y are assumed as known. The value α is first estimated and the values σ, σ_x, σ_y, calculated by equations given below (58), (59), (61). Then from equation (57) a more accurate value is obtained for α. If necessary, the procedure is repeated.

The tensile stress σ in the skin in the direction of the tension diagonals is

$$\sigma = (T/\pi r_H^2 \delta)\,(1/\sin 2\alpha) \quad . \quad . \quad . \quad . \quad (58)$$

where r_H = radius of curvature and δ the wall thickness of the metal skin.

The normal stress

$$\sigma_x = -(T/n r_H F_z)\cot\alpha \quad . \quad . \quad . \quad . \quad (59)$$

is produced in the longitudinal stiffeners through the fields of tension diagonals in the outer skin. n is the number of the longitudinal stiffeners and F_x the cross-sectional area of a longitudinal stiffening.

Owing to the deflection of the tension diagonals at the longitudinal stiffeners, a radial load directed inwards is exerted by the skin on each longitudinal stiffener.

Using p to denote this load per unit length and assuming that p is invariable over the longitudinal stiffener, we get

$$p = (T/n r_H^2)\,tg\,\alpha \quad . \quad . \quad . \quad . \quad . \quad (60)$$

The longitudinal stiffeners are thus to be calculated for bending due to axial compression.

At the points of connection between longitudinal stiffeners and transverse members the longitudinals transmit their load $p \cdot t$ to the transverse member (t = distance between transverse members). Owing to the individual loads directed radially inwards on the transverse members, a normal stress σ_y and a maximum local bending stress σ_b is produced in the transverse member. This will be

$$\sigma_y = -(Tt/2\pi r_H^2 F_y)\,tg\,\alpha \quad . \quad . \quad . \quad . \quad (61)$$

and

$$\sigma_b = (\pi/6)\,(Tt/n^2 k F_y)\,(r_s/r_H^2)\,tg\,\alpha \quad (n \geqq 6) \quad . \quad . \quad . \quad (62)$$

where F_y = cross-section of the transverse member.

r_s = radius of the middle fibre of the transverse member.

$k = W/F_y$ (W = moment of resistance of the cross-section of the transverse member).

If the critical torsional moment T_{kr}, at which the plate bulges between the stiffeners is of the same order as T, T in formulæ (58) to (62) must be replaced by $T - T_{kr}$.

The ratio between bending and normal stress is

$$\sigma_b : \sigma_y = (\pi^2/3)\,(r_s/n^2 k) \quad . \quad . \quad . \quad . \quad (63)$$

If the transverse members are riveted to the skin, part of the load directed radially inwards and exerted by the outer skin on the framework of the stiffeners, will be directly transmitted to the transverse members. In this case we should be on the safe side by using the above formulæ for the calculation of the stiffeners.

SUMMARY.

The present report is a survey of simple formulæ and methods of calculation hitherto published for the determination of stability and strength in the case of structures covered with thin sheet metal (plate and shell structures) in aeroplane construction. In particular, it deals with the calculation of isotropic, orthotropic and stiffened rectangular plates, circular cylindrical partial and solid shells under various types of load. Reference to the relevant literature which is given at the end of each section will assist in the closer study of the questions dealt with.

ABSTRACTS OF PATENT SPECIFICATIONS.

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

These abstracts are compiled by permission of the Controller of His Majesty's Stationery Office. Official Group Abridgments can be obtained from the Patent Office, 25, Southampton Buildings, London, W.C.2, either sheet by sheet as issued on payment of a subscription of 5s. per group volume or in bound volumes 2s. each, and copies of full specifications can be obtained from the same address, price 1s. each.

AEROPLANES—CONSTRUCTION.

448,705. *Improvements in and relating to Aircraft Tailplanes.* Coats, A. G., Gloucester House, Park Lane, London, W.1, and Hafner, R., Mantlergasse 47, Vienna, 13, Austria. Dated December 12th, 1934. No. 35,705.

In the case of aircraft having rotatable wings or any aircraft descending at large angles of incidence, it is stated that tailplanes of normal design become unstable. It is therefore proposed that the whole of the tailplane shall be rotatable about a horizontal axis so that it may have the same angle as the air flow. As this angle may be large an automatic slipping device is fitted so that if, after attempting to land, the pilot changes his mind, the tailplane automatically returns to the normal position under the action of the slipstream.

AEROPLANES—GENERAL.

448,344. *Improvements in Aeronautical Machines of the Annular Aerofoil Type.* Porter, J. R., Whatley Road, Clifton, Bristol. Dated December 8th, 1934. No. 35,310.

The aircraft proposed has two circular aerofoils, looking like a ring in the front view, each of which contains circular nacelles which are curved longitudinally. The inner sides of the aerofoils form the sides of a circular fuselage.

ARMAMENT.

447,931. *Improvements in or relating to the Mounting of Guns on Aircraft.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex; Lobelle, M. J. O., Ludlow, 298, Langley Road, Langley, Bucks; and Trotter, J. C., 488, Cheetham Hill Road, Manchester. Dated February 5th, 1935. No. 3,731.

It is proposed to fit a gun mounting in the nose of an aeroplane fuselage. The mounting is contained in a cone-shaped nose piece which continues the curves of the fuselage. The nose piece is so mounted that it can be rotated on

a horizontal axis, and it has a slot through which the gun can be fired. The gun is mounted on a U-shaped piece contained within this nose piece and the gun pivot itself is carried on an extension which is outside the nose piece. The U piece is mounted on a horizontal cross axis and can be rotated on this axis. The mounting may be driven by an electric motor through a friction gear.

CATAPULTS.

450,265. *Improvements in or relating to Arrangements for Launching Aircraft.* Salmon, P., Royal Aircraft Establishment, South Farnborough, Hants. Dated March 7th, 1935. No. 7,125.

This specification refers to the launching of flying boats by means of a catapult mounted on a special vessel. At one end of this vessel a closable dock is provided into which the flying boat can be floated, there are also means for causing the flying boat to engage with the launching gear of the catapult, which latter is mounted on the deck. The dock may be raised or lowered in the water or the trim of the vessel may be altered or water may be pumped out of the dock.

CONTROL OF AIRCRAFT.

448,343. *Improvements in and relating to the Operation of Flaps on Aircraft.* Automotive Products Co., Ltd., Brock House, Langham Street, London, W.1, and Brown, F. V., of the same address. Dated December 6th, 1934. No. 35,085.

In the case of the jack and pump device, referred to in British Specification No. 428,252, it is proposed to add a pressure relief valve controlled by an adjustable spring, so that the flaps can return to an inoperative position when the pressure in the system reaches a predetermined figure. The pump used may be of the reversible flow type to actuate the operating unit in both extension and contraction.

448,827. *Improvements in or relating to Control Surfaces for Aircraft.* McMahon, A., 28, Hellington Street, Edinburgh, Scotland. Dated December 19th, 1935. No. 35,188.

It is proposed to use for aircraft control members tailplanes and elevators only. These have a dihedral angle and are adopted to be rotated as a whole by a manually operated control. To change direction the tailplanes are rotated as a whole and the elevators are operated.

448,025. *Improvements relating to the Control of Aircraft.* Tyannetakis, G. P., Hotel Ersi, Old Phaleron, near Athens, Greece. Dated August 27th, 1934. No. 24,687. This application has become void.

In order to provide lateral control in aircraft, it is proposed to replace the usual ailerons by separate planes which are arranged either above or below the wing at some position approximating to the centre of the chord. These planes extend along the wing and are of normal aerofoil section, preferably symmetrical, and are of high aspect ratio. Control is effected by altering the angle of these planes through the usual controls.

DESIGN AND CONSTRUCTION.

450,276. *Improvements in Aircraft Control Gear.* Handley Page, Ltd., Lachmann, G. V., Volkert, G. R., and Dare, W. J., all of 40, Claremont Road, Cricklewood, Middlesex. Dated May 14th, 1935. No. 14,116.

This is a mechanism for operating aircraft controls, such as ailerons or flaps, where the control surface is moved backwards at the same time that its angle is increased. In one example the flap is hinged to the rear of a member which is slidable in the wing by a system of links the ends of two of which are also

attached to the flap. Another link operates the two links first mentioned as well as the slidable member, and as a result the flap is moved backwards and depressed. In another example the flap is carried on links, only the slidable member being omitted. In the case of a slotted flap the slot may be closed when the flap is in its normal position.

450,395. *Improvements in and relating to Structures Formed of Metal or Fabric Sheetings.* Lamb, C. F., 4, Cleveland Square, St. James' Street, London, S.W.1. Dated October 9th, 1934. No. 16,163.

In order to attach thin sheets of metal or fabric to the wings, etc., of aircraft, it is proposed that the sheet be thickened at the edges by welding a piece in place or by spraying the part with metal. The thickened edges may be on one side only of the sheet, may be drilled for screws or the like, or the sheets may be bent for attachment purposes, the thickened edges then acting as a lock. The joints between the sheets may be sprayed with metal after assembling.

447,377. *Improvements in Folding Self-Supporting Cantilever Wings for Aircraft.* The Blackburn Aeroplane and Motor Co., Ltd., Seaplane Base, Brough, Hull, E. Yorks, and Bumpus, F. A., Elloughton, Brough, Hull, E. Yorks. Dated May 29th, 1935.

In order to fold the wing of a cantilever monoplane against the fuselage of the machine it is proposed to hinge the stub wing and the main wing together by means of a hinge having an obliquely inclined axis. Aft of the hinge there is an external junction face which forms approximately a part of the surface of a core. The front connection of the wing to the stub wing is of normal design.

447,459. *Improvement in or relating to Aircraft Wings.* Dornier Metallbauten, G.m.b.H., and Dr. Ing. C. Dornier, Friedrichshafen, Lake Constant, Germany. Convention date (Germany), August 30th, 1934.

It is proposed to construct aeroplane wings by using two spars connected by braced frames arranged as in Warren bracing. The covering is arranged by triangular plates which are attached to the spars and to the braced frames.

447,520. *Improvements in or relating to Spars for Aircraft Wings.* Short Bros., Ltd., and Gouge, A., both of Seaplane Works, Rochester, Kent. Dated May 31st, 1935. No. 15,822.

The spar described has T section flanges which are connected together by tubular members arranged as in a Warren girder. The T heads are shaped to the camber of the wing and the skin is riveted direct to them. The tubular members have fittings made of H section metal where the legs of the H have been bent to conform with the interior radius of the tube. These are then riveted together and the fitting and the flanges are connected by gusset plates.

449,148. *Improvements in or relating to Aircraft.* Grandjean, A., 51, Avenue Alphand, Sainte Maude, France (Seine). Dated September 14th, 1934. No. 26,450. This application has become void.

It is proposed to lift an aircraft in the air by forming within its fuselage a sort of wind tunnel through which air may be induced by a fan. In this tunnel a number of aerofoils are arranged, and it is the action of the induced flow on these which, it is stated, cause the machine to rise. The incidence of the aerofoils may be changed and there is also a honeycomb in the tunnel while a propeller is fitted for forward propulsion.

448,249. *Improvements relating to Internally Trussed Structures which are Capable of Flexing Longitudinally.* Grant, C. H., 51, Prospect Street, New Rochelle, Westchester, Now York, U.S.A. Convention date (U.S.A.), December 9th, 1933.

This is a device for altering the camber of aircraft wings. The ribs are constructed with an arrangement of linkages, one end of which is slidable so that by movement of a control point the camber of the wing is altered. The top surface of the wing is flexible while the underside is composed of panels which slide on each other.

448,324. *Improvements in and relating to the Construction of Frame Members for Aircraft.* Martin, J., Higher Denham, Uxbridge. Dated December 7th, 1935. No. 33,990.

It is proposed to construct a spar for aircraft by using tubes running longitudinally connected by members so as to form a type of lattice girder. The spar may be triangular or square in section, etc. The bracing members are attached to lugs attached to the tubes.

448,343. *Improvements in and relating to the Operation of Flaps on Aircraft.* Automotive Products Co., Ltd., Brock House, Langham Street, London, W.1, and Brown, C. V., of the Company's address. Dated December 6th, 1934. No. 35,085.

It is proposed to actuate the flaps by means of a hydraulic jack. In the pipeline conveying the liquid to the jack a pressure relief valve is provided, adapted to open when the jack is subjected to a predetermined pressure and to allow the jack to approach its inoperative position.

ENGINES.

447,283. *Improvements in Cowling for Liquid-Cooled Internal Combustion Engines.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby. Dated November 15th, 1934. No. 32,898.

In this arrangement it is proposed to use a radiator of horseshoe shape fitted below the engine. The exhaust gases are collected from the manifolds by pipes which may be of D shape and are fitted so as to be flush with the cowling, while the gases themselves are discharged through nozzles placed in cowling behind the radiator through a type of venturi so as to increase the air flow through the radiator. An oil cooler may be formed in the outer wall of the radiator tunnel, and alternative arrangements are described for attaining the same results.

449,139. *Improvements in Aircraft Propelling Devices.* Trabucien, J. J., 36, Avenue d'Iena, Paris, Seine, France. Convention date (France), December 4th, 1934.

The apparatus described consists of a gear driven by the engine which drives two propellers, mounted coaxially, in opposite directions and which, it is claimed, eliminates torque on the aircraft. The gear described is of the floating type and consists of a bevel when driven by the engine which drives two or more planetary bevels mounted on a rotatable spider. These in turn drive two smaller planetary bevels which drive two bevel sun pinions which, respectively, drive the two propellers in opposite direction.

447,968. *Turbo-Compressor for Air-Cooled Aircraft Engines.* Société Rateau, 40, Rue du Colisée, Paris, France. Convention date (France), February 16th, 1935.

The arrangement described is suitable for a two-row radial air-cooled engine. The exhaust gases are collected by tubular exhaust pipes in the usual manner,

and there are two exhaust turbines driving air compressors situated behind the engine. Each exhaust turbine and its compressor is arranged radially, the exhaust turbines being behind the cylinder heads and the compressors inside the cowling.

448,523. *Improvements relating to the Arrangement of Lubricant Reservoirs for Aircraft Engines having Cowlings.* Armstrong Siddeley Motors, Ltd., and Fell, L. F. H., both of Armstrong Siddeley Works, Park Side, Coventry, Warwickshire. Dated January 11th, 1935. No. 1,004.

It is proposed to arrange the oil sump of an air-cooled radial engine so that it fits in place of a piece cut out of the cowling. The outer wall of the sump may form part of the cowling and may have radiating fins which latter may be in a passage leading to the air intake of the carburettor.

ICE FORMATION.

449,532. *Means for Automatically Preventing Detrimental Ice Formation in Aircraft.* Swan, A., Griffith, A. A., and Helmore, W., all of the Royal Aircraft Establishment, South Farnborough, Hants. Dated December 21st, 1934. No. 36,607.

This specification refers to means whereby any known method of preventing ice formation in aircraft can be brought into action automatically when ice formation conditions are present. The device proposed consists of two apertures facing forward in the case of an apparatus intended for use on aircraft wings. Each aperture is connected by a pipe, one to each side of a flexible diaphragm which is normally inactive as there is equal pressure on each side of it. But one aperture is considerably smaller than the other, and it is stated that in ice forming conditions the small aperture becomes quickly blocked. When this happens the pressure on each side of the diaphragm becomes unequal and the diaphragm moves. This movement can be caused to actuate the prevention mechanism either directly or via a relay. A similar device is described for use in connection with carburettors.

MISCELLANEOUS.

442,009. *Improvements in or relating to Propeller Wheels.* Smith, H. A., Haseltine, Lake and Co., 28, Southampton Buildings, Chancery Lane, London, W.C.2. Dated July 25th, 1934. No. 21,782. (Communication from Zegers, A., Edificio La Mutual de la Armada, 9, Piso, Oficina, 1, Santiago, Chile.)

This specification describes a wheel carrying vanes intended to be completely immersed in the fluid in which it is to be used for propulsion. The vanes are arranged to turn about an angle of 90° in appropriate portions of the wheel periphery by means of an eccentric cam ring which actuates rods, which, in their turn, act on cam-shaped projections on the blades. There are also pins to limit the turning of the blades.

PARACHUTES.

449,324. *Improvements in Parachute Packs for Aviators.* G.Q. Parachute Co., Ltd., Quilter, R. C., and Gregory, J., all of 17, Stoke Road, Guildford, Surrey. Dated December 21st, 1934, No. 36,745, and May 24th, 1935, No. 15,154.

In this pack it is proposed that the cone or cones which co-operate with the eyelets on the closure flaps of the pack to hold the latter closed are attached to the base of the pack as distinct from to one of the closure flaps. The pack may be employed as a seat pack or adopted to be fitted to the person of the pilot, and is arranged by means of a number of compartments to be flexible so as to be convenient to wear.

PERFORMANCE.

448,737. *A Method of and Apparatus for Navigating Aircraft during Landing.* Siemens Apparati und Maschinen Gesellschaft mit beschrankter Haftung, 4, Askanischen Platz, Berlin, S.W.11, Germany. Convention date (Germany), May 19th, 1934.

This specification deals with fog and similar landings and is concerned with the navigation in the vertical sense only. The distance of the point at which the landing is begun from the landing point is determined by measuring the time taken by the aircraft to fly over a path of reference, say, two signals. Afterwards the altitude of the aircraft is controlled in accordance with a predetermined altitude time curve which is independent of the wind velocity prevailing at the time.

ROTOR CRAFT.

447,066. *Improvements in or relating to Rotating Wing Aircraft.* Coats, A. G., Gloucester House, Park Lane, London, W.1, and Hafner, R., Mantlergasse 47, Vienna, 13, Austria. Dated November 9th, 1934. No. 32,339.

In the case of aircraft with rotating wings it is stated that difficulties arise with the clutch gear when the rotor is being accelerated. It is proposed to avoid these difficulties by the use of a dog clutch in combination with a fluid flywheel. Arrangements are made so that the wheel brakes must be on when the clutch is connected, though the brakes can be applied without operating the clutch.

448,703. *Improvements in or relating to Aircraft Fuselages.* Coats, A. G., Gloucester House, Park Lane, London, W.1, and Hafner, R., Mantlergasse 47, Vienna, 13, Austria. Dated December 12th, 1934. No. 35,702.

This fuselage is intended for aircraft of the autogiro type in which the angle of incidence of the fuselage during descent may be large. It is proposed, therefore, to arrange that vertical sections through the fuselage shall be of streamline form. It is also proposed to fit slots and flaps to the lower portion of the fuselage and there may also be split flaps arranged along the top. The rudder hinge is sloped forward.

448,704. *Improvements in or relating to Rotative Wing Aircraft.* Coats, A. G., Gloucester House, Park Lane, London, W.1, and Hafner, R., Mantlergasse 47, Vienna, 13, Austria. Dated December 12th, 1934. No. 35,703.

It is proposed to construct the cabane carrying the hub of the rotor of a rotative winged aircraft with three struts, the rear two being fixed to the hub bracket and hinged to the top of the fuselage, while the front one is pivoted to the hub by a ball and socket joint and is also hinged to the fuselage. It is claimed that the arrangement facilitates the transmission of the torque when the rotor is power driven.

448,349. *Improvements in or relating to Rotative Wing Aircraft.* Coats, A. G., Gloucester House, Park Lane, London, and Hafner, R., Mantlergasse 47, Vienna, 13, Austria. Dated December 12th, 1934. No. 35,704.

In the case of a helicopter it is desired that each blade shall be connected to the hub by a torsionally flexible radial tension member and a method of fixing this member is described. At the outer end it is screwed into the blade, an inner extension of which is screwed externally and split, a normal nut being screwed on in order to lock the parts together. In the attachment at the inner end the end of the torsion member itself is screwed and split, the locking being accomplished by wedging this screw apart by means of a taper plug.

442,013. *Improvements relating to Aircraft.* Kay Gyroplanes, Ltd., Kay, D., and Dyer, J. W., all of 18, Atholl Crescent, Edinburgh, Scotland. Dated July 27th, 1934. No. 22,019.

This specification refers to aircraft of the autogiro type in which the incidence of the blades of the rotor is variable. Arrangements are made so that the rotor may be spun up by the motor with the rotor blades at negative angles and that the incidence of the blades may be increased and the motor disconnected so that the machine may be made to jump off the ground. A description is given of the control mechanism which consists of a pawl and ratchet device so that the angles of incidence of the blades, the engine clutch and dog clutch are interconnected so that when the incidence has been adjusted to a predetermined position it automatically brings about the withdrawal of the clutch.

442,014. *Improvements relating to Aircraft.* Kay Gyroplanes, Ltd., Kay, D., and Dyer, J. W., all of 18, Atholl Crescent, Edinburgh, Scotland. Dated July 27th, 1934. No. 22,020.

Aircraft rotors of the autogiro type are referred to, and it is proposed to rotate the rotor by the engine until the necessary speed is attained and then to disconnect the engine. The engine-driven pinion engages with a gear wheel on the rotor hub and is arranged so that it can be swung into or out of mesh with the gear wheel by movement in a curved path the plane of which is parallel to the plane of rotation of the wheel, the arrangement being such that the setting of the pinion and gear wheel in the vertical direction relative to the rotor hub supporting structure remains undisturbed at all times.

448,560. *Improvements in or relating to Power Transmission Mechanism for Aircraft.* Yoxall, J., York House, Deganwy, North Wales, and Propello Inventions, Ltd., 105, Cheyne Walk, Chelsea, London, S.W.10. Dated December 14th, 1934. No. 35,947.

In aircraft of the autogiro type it is stated that considerable trouble occurs owing to the burning of the elements of the clutch situated between the rotor and engine, owing to the considerable degree of slipping necessary. In order to obviate this it is proposed to transmit the power through a hydraulic coupling having two or more rotatable elements, one being connected to the engine, the other to the rotor. A dog clutch is also fitted.

SEAPLANES.

448,581. *Improvements in or relating to Floats for Flying Machines.* Masaji Nojiri, 29, Komagome Sakashila-cho Hongo-ku, Tokyo, Japan. Dated April 30th, 1935. No. 12,815.

This specification describes a seaplane float which is arranged to be collapsible in flight with the object of reducing the air resistance of the aircraft. The float is of prismatic shape and the front and rear walls are movably connected with the top and bottom walls and the two side walls are movably connected with the bottom wall, which is attached to the hull by struts. An envelope is within the float so that the pilot can expand the float when desired.

UNDERCARRIAGES.

447,448. *Retractable Landing Gear for Aeroplanes* Société d'Inventions Aeronautiques et Mecaniques, S.I.A.M., 1 Route des Alpes, Fribourg, Switzerland. Convention date (France), February 4th, 1935.

This arrangement relates to improved retractable landing gear for aeroplanes of the type in which a wheel describes two rotational movements about two distinct axes, the two rotations being combined and proceeding simultaneously and the resultant movement being determined by the presence of a member of

constant length which connects a fixed point on the aeroplane with a fixed point on the leg. The landing gear has a single jack of the double acting type which affects the two rotational movements in both directions or a separate jack may be used for each.

448,104. *Improvements in the Braking of Aircraft.* Bendix Aviation Corporation, 105, West Adams Street, Chicago, Illinois, U.S.A. Convention date (U.S.A.), August 31st, 1933.

In this arrangement the wheel brakes are applied through the rudder bar. The latter, in addition to the usual rudder control cables, is connected by means of links to an arrangement of pistons working in cylinders. These are normally connected by passages so that the liquid with which they are filled can flow from one to the other during flight so as not to interfere with the rudder operation. When it is desired to use the brakes pressure is induced in the system by the operation of additional pistons by manual control, at the same time the passages connecting the cylinders are cut off. The result is that pressure is supplied to the brakes equally when the rudder bar is central, but when the bar is moved the brakes are applied unequally.

447,573. *A New Braking System for Aeroplanes.* J. M. Cabellos de Oropesa, 113, Calle de San Bernardo, Madrid, Spain. Convention date (Spain), December 20th, 1934.

It is proposed to arrange an endless chain in the tail of an aeroplane and to revolve this backwards when the aeroplane has landed. It is stated that the result will be to pull the machine up quickly, without compensating disadvantages.

447,610. *Improvements in or relating to Retractable Undercarriages for Aircraft.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Ordidge, F. H., Soircroft, Croft Gardens, Ruislip. Dated October 18th, 1934, No. 29,839, and March 22nd, 1935, No. 9,031.

The retractable chassis described has a landing wheel carried by two members, one of said members being pivoted on a fixed portion of the aircraft and the other to a block movably secured on a guide, the second member being substantially perpendicular to the guide when the undercarriage is fully extended. The guide has a rack and the block has a pawl so that on lowering the undercarriage the pawl rides freely over the rack. Means are provided for disengaging the pawl when retracting the undercarriage. Various different modifications are described.

449,702. *Improvements relating to Brake Control Mechanism for Aircraft.* Bendix, Ltd., King's Road, Tyseley, Birmingham, and Lambert, A. W., of the same address. Dated February 20th, 1935 No. 5,406.

This specification describes an arrangement by which the instructor in a dual controlled aircraft can take over the control from his pupil when desired. In the case of the pupil's brake control, the instructor can, by moving a separate control, unlock a plunger operated by the pupil from a barrel which is connected with the brake. The brake can then only be applied by the instructor.

449,728. *Improvements in or relating to Undercarriages for Aircraft.* Ceskomoravska-Kolben-Danek Co., Ltd., 36, Palackeho, Prague X, Czechoslovakia, and Jaroslav Slechta, 399 Obvodova, Prague IX, Czechoslovakia. Convention date (Czechoslovakia), September 29th, 1934.

The undercarriage described consists, in front view, of two members, one projecting from the underneath part of the fuselage, the other from its side. The characteristic of the device is that the latter member is connected to a shock-absorbing device of normal type which is contained completely within the hub of the wheel.

448,983. *Improvements in Undercarriages for Aircraft.* Dr. Ing. N. C. F. Porsche, G.m.b.H., Kronenstrasse 24, Stuttgart, N., Germany. Convention dates (Germany), November 2nd, 1934, and November 3rd, 1934.

This device relates to undercarriages employing torsion springs and means are provided for retracting the undercarriage without increasing the tension of the torsion springs. Hence in retracting the undercarriage it is only necessary to lift the weight. In one example the torsion spring acts as a pivot for retracting the undercarriage, which is claimed to reduce the number of required parts. Retraction is allowed through the abutment of the torsion spring being adjustable, say, through gearing. When the undercarriage is extended the spring abutment is rigidly fixed, which is also the case when the undercarriage is retracted.

REVIEWS.

GUIDE FOR FLYING INSTRUCTORS.

Published by the Guild of Air Pilots and Air Navigators of the British Empire. Price 5/6.

As the Guild of Air Pilots has been entrusted by the Air Ministry with the task of enquiring into the competency of flying instructors and of granting certificates to those who are approved, it has been thought necessary to issue a handbook on the subject. The result is that there is now available an excellent little work on flying tuition which could be read with advantage by the pupils as well as by the instructors.

The book is full of information and hints concerning piloting in all its phases. Detailed directions concerning the handling of aeroplanes under all conditions are given, as well as advice about what to do in emergency. The whole is obviously the essence of the experience of many competent pilots.

There are, at the same time, one or two matters which should be reconsidered when a second edition is called for. On page 7 it is stated that the possession of a Guild certificate entitles a holder to obtain an instructor's endorsement on his licence; on page 4 it is stated that the certificate is taken by the Air Ministry merely as evidence of competency. It is presumed that the latter is correct, as it may happen that facts are known to the Air Ministry which may make it undesirable for a particular person to instruct, in spite of technical competency. On page 23 the effect of dihedral angle on a sideslipping aeroplane should be noted. Under these conditions the outer wing has its incidence angle increased and the inner wing has the same angle reduced, and banking follows automatically. On page 26 it is stated that airscrew pull, the speed of the aeroplane, and the lift of the wings, are forces. Speed is not a force.

These are, however, faults which are not serious and are easily corrected and they do not alter the fact that the book is the best manual on practical piloting which has yet appeared.

FLIGHT TO-DAY.

By J. L. Nayler, M.A., F.R.Ae.S., and E. Ower, B.Sc., F.R.Ae.S. Published by Oxford University Press. Price 3/6.

This book is very welcome. When two well-known aeronautical experts like Messrs. Nayler and Ower write a book with the specific intention of conveying aeronautical information to the ordinary man, it is natural to expect that the information will be accurate and that it will be displayed without frills.

Whether the general public will insist on having their appetites whetted for aviation information by references to giant air liners, battleships of the air,

pilots with frozen eye-balls, and the like, I do not know, but it is quite certain that those who do want to understand something about aviation, and who want that information to be clearly given, would be well advised to read this book. It covers adequately all the usual aspects of the subject and is really well illustrated.

There are one or two inaccuracies which should be corrected in later editions. The " Blimp " was a single-engined airship and many of them had fuselages similar to the, then, normal B.E.2 type. The statement that a test for porpoising of model seaplane hulls in a tank has only been applied recently is not correct. Tests were carried out on this matter in the N.P.L. tank at least fifteen years ago. The last error really deserves a quotation. Referring to the Macchi seaplane, which holds the world's speed record, the authors state, correctly, that it has two propellers revolving concentrically in opposite directions. They ascribe this to the engine " having two crankshafts, one revolving inside the other—a remarkable mechanical feat." It would, indeed, be a remarkable mechanical feat, were it true, but one's admiration for the mechanical ingenuity ascribed to the Italians is tempered by the reflection that " crankshaft " is an error for propeller shaft.

THE NEW MODEL AEROPLANE MANUAL.

By L. H. Sparey and C. A. Rippon. Published by Percival Marshall and Co., Ltd. Price 3/-.

The making and using of models is an amusement that fascinates mankind. Whether it is the intricate layout of a complicated model railway, the building and sailing of model yachts, or the making and flying of model aeroplanes, the appeal seems mainly to consist in the watching of the work of one's hands doing precisely what one intended.

From this point of view the making of model aircraft possesses advantages. Not only is the construction of a simple model extremely easy, but it flies in precisely the same manner as a full-sized aeroplane, is disturbed in its flight by the same air currents, and is subject to the same accidents.

This particular book is the best of its type that has appeared so far. Not only does it illustrate and describe the improvements in construction and materials which have resulted from experience, but it describes clearly the newer ways of doing things and the authors are not afraid to include an occasional formula.

But it is not easy to see why the reader who can apply the formulæ for rubber motors should not be encouraged to use the more simple aerodynamical formulæ and data. Why not publish the ordinates of a few wing sections instead of giving drawings? Why not give lift and drag curves of the selected sections, and the simple formula for aspect ratio corrections? In fact, why not encourage the aero-modelist to design his model in the same way that the full-sized machine is designed, to work out its performance before he builds it, and to balance the known aerodynamical advantage of increasing the aspect ratio against the increased weight of the wing of larger span? Those readers who are frightened of formulæ would skip the pages devoted to them, but I believe there are many who would welcome encouragement to put their work on a scientific basis.

MIXTURE STRENGTH IN PETROL ENGINES CONTINUOUSLY CONTROLLED BY ELECTRIC EXHAUST GAS ANALYSERS.

By G. D. Boerlage and L. A. Peletier.*

During the last few years continuous indicating electric exhaust gas analysers have been coming into use more and more for controlling the strength of the fuel/air mixture which the carburettor feeds into the engine.

These instruments have already been described in a publication (*vide* List of References (1)), but since they are of growing interest, especially for aviation, some further research as to their merits and shortcomings seems to be indicated.

Therefore tests have been run with an aircraft type of instrument (the " Cambridge (N.Y.) Aero Mixture Indicator ") and an automobile type of instrument (the " Lantz Phelps Motor Fuel Combustion Tester ").

I. Principles.

The function of the instruments investigated is based on the different thermal conductivity of the components in the exhaust gas. In Table I some data are given derived from the tables of Landolt and Börnstein :—

Table I.

	Thermal Conductivity. K cal./m.h.C.	Calculated for air = 100.
Carbon dioxide, CO_2	0.013	62
Carbon monoxide, CO	0.019	91
Nitrogen, N_2	0.021	100
Oxygen, O_2	0.021	100
Air	—	100
Methane, CH_4	0.026	124
Hydrogen, H_2	0.150	715

As is shown in the aforementioned table the thermal conductivity of N_2, O_2 and CO is practically the same. The thermal conductivity of CO_2, however, is lower, whereas H_2 has a much higher thermal conductivity. Thus it may be concluded that the combustion indicator investigated is not a CO-meter, but responds mainly to the CO_2 and the H_2 contents in the exhaust gases. Now it is a well-known fact that the composition of the exhaust gases varies considerably with the fuel/air ratio of the mixture entering the cylinder.

At a fuel/air ratio of, for instance, 1 : 11 (0.09), which means a very rich carburettor setting in practice, the influence of the relatively small quantity of H_2 with a high thermal conductivity is even greater than the influence of the greater quantity of CO_2 with a low thermal conductivity. So the heat conductivity of the exhaust gas is higher than that of air

At a fuel/air ratio of, for instance, 1 : 13 (0.077), which means a normal carburettor setting in practice, there will be less H_2 and more CO_2 in the exhaust gas than in the former example. It appears that now the effect of the H_2 balances the effect of the CO_2 present. So here the heat conductivity of the exhaust gas is equal to that of air.

* Of the " Delft Laboratory," Delft, Holland. (Royal Dutch Shell Group).

At a fuel/air ratio of, for instance, 1 : 14.8 (0.068), being the value for theoretically complete combustion for an average petrol and which means a lean carburettor setting in engine practice, there will be practically no H_2 in the exhaust gas, but the CO_2 content will be still higher than in the former case. So the heat conductivity of the exhaust gas is less than that of air.

At a still lower fuel/air ratio, for instance, 1 : 17 (0.059), which means a very lean if not an impracticable carburettor setting in engine practice, there will be no H_2 in the exhaust gas and the quantity of CO_2 will be *lower* than in the former example. From this it follows that for very lean mixtures the thermal conductivity of the exhaust gas in itself is no longer a criterion for the fuel/air ratio. Fortunately such lower fuel/air ratios are beyond the range of practical use.

The question arises whether and to what extent the relation between thermal conductivity and fuel/air ratio will be dependent on the chemical composition of the fuel and on engine conditions. The main components of exhaust gas are N_2, CO_2, CO, H_2O, H_2, O_2 and CH_4 or heavier hydrocarbons. When the values of four of these variables are known, for a fuel with a given H/C ratio, the remaining variables and the air factor (that is, the actual fuel/air ratio divided by the fuel/air ratio for theoretically complete combustion) can be calculated. In the literature many exhaust gas analyses of petrol engines are given. For instance, useful data are furnished in three papers which were published recently (*vide* List of References (2), (3) and (4)).

It will be seen from these papers that a small percentage of O_2 is always present, even with rich mixtures. This percentage may be fixed at 0.3 per cent. when the air factor is greater than 1.0. It will be clear that for very lean mixtures (air factor smaller than 1.0) the percentage of O_2 is greater than 0.3 per cent.

The CH_4 content appeared to be very small too, varying from 0.2 to 0.3 per cent., dependent on the fuel/air ratio. Without introducing a considerable error this percentage may be fixed at 0.25.

With these assumptions for the values of O_2 and CH_4 only two further variables have to be known for calculating the other variables and the air-factor. However, in practice it appears that the knowledge of one variable will be sufficient, because of the fact that there is a fixed relation between the percentages CO, CO_2 and H_2 in the exhaust gas of an I.C. engine.

D'Alleva and Lovell (General Motors) (*vide* List of References (4)) ascribe this fixed relation to the water-gas equilibrium :—

$$CO_2 + H_2 \rightleftarrows CO + H_2O.$$

They claim that an apparent equilibrium is reached, defined by the relation

$$(CO \times H_2O)/(CO_2 \times H_2) = K \text{ (constant)}.$$

The constant of this equilibrium depends mainly on temperature. The average value of K for exhaust gases is determined by experiment to be 3.77. The deviations from this value appeared to be great (mean error 10 per cent.). As, however, the value of K is computed from four values, of which the H_2 percentage in particular has a large relative error, it is reasonable to expect that the value K is subject to an error of the above-mentioned magnitude.

Influence of H/C Ratio on Instrument Reading.

As the instrument reacts to CO_2 and H_2 it is reasonable that the readings are dependent on the H/C ratio of the fuel. Thus the calibration of the instrument in fuel/air ratio holds only for one given H/C ratio. So it is necessary to ascertain the differences in H/C ratio for different fuels and to investigate their quantitative influence on instrument reading.

Fig. 1 shows the H/C ratio of pure hydrocarbons and alcohols. It is seen that the H/C ratios of the paraffinic and naphthenic compounds which are present

in normal petrols do not differ very much. The H/C ratios of benzene, toluene and xylene, however, are much lower and those of alcohols much higher than the H/C ratios of the aforementioned paraffinic and naphthenic compounds.

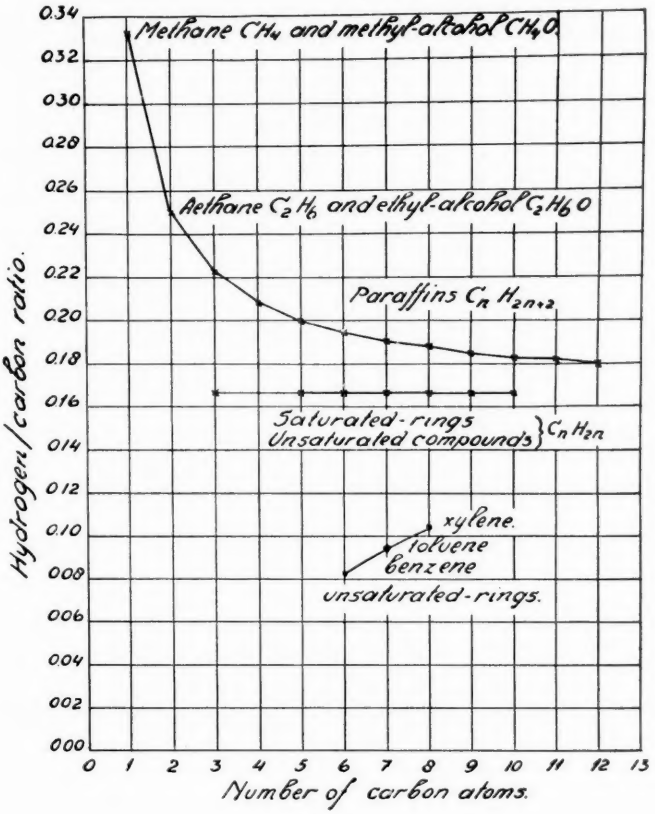

FIG. 1.

Relation between hydrogen/carbon ratio and number of C-atoms for different types of hydrocarbons.

Fig. 2 shows the H/C ratios of some alcohol-free automotive and aviation petrols. As expected, a relation exists roughly between aromatic content and H/C ratio; the H/C ratio can be determined from the aromatic content with an accuracy of ± 0.01.

As the scale of the Cambridge instrument has been calibrated in fuel/air ratio for an average value of H/C ratio, a fuel with a lower H/C ratio, *e.g.*, benzene, is indicated too lean. This means that the real fuel/air ratio is higher than indicated. On the contrary, the mixture strength of a fuel with a higher H/C ratio, *e.g.*, ethane, is indicated too *rich*. In section IVe figures will be given concerning the quantitative influence of H/C ratio (aromatic content) on instrument deviation. Further, it will be shown that when calibrating the instrument in air factor the deviation for fuels with different H/C ratio will be less. This means an advantage, as the ideal combustion tester should not indicate fuel/air

ratio but air factor, the latter being the direct criterion for the completeness of combustion.

An interesting case is presented by alcohol. Though the H/C ratio of ethyl-alcohol is equal to that of ethane, the instrument, contrary to expectations, gives *too* small an indication of the fuel/air ratio by weight. The explanation of this lies in the fact that alcohol contains per kilo less carbon and hydrogen than petrol, due to the presence of oxygen. In this case, too, the instrument responds better to air factor than to fuel/air ratio.

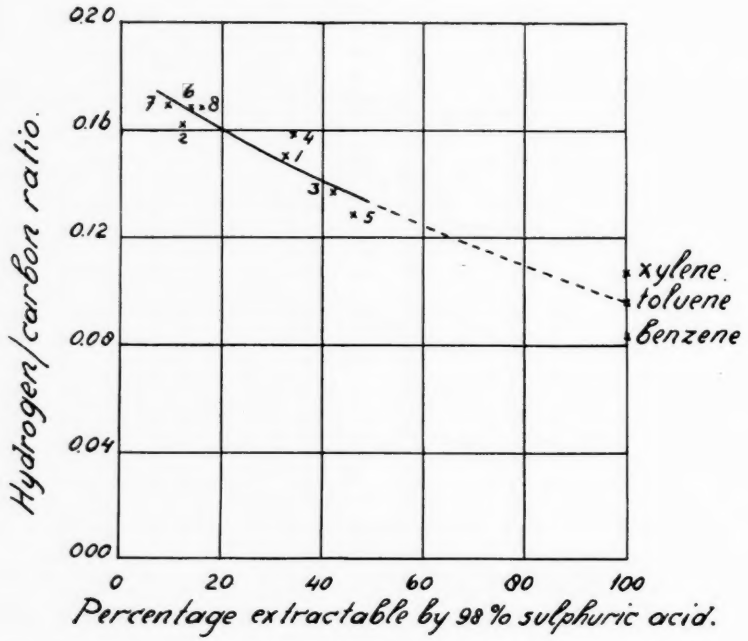

FIG. 2.

Relation between hydrogen/carbon ratio and aromatic content for some petrols of different composition.

II. CONSTRUCTION OF THE INSTRUMENTS.

In the instruments investigated the thermal conductivity of the exhaust gas is compared with the thermal conductivity of a standard gas (*e.g.*, air saturated with water vapour) by comparing the electrical resistances of wires of metal with a high temperature coefficient, surrounded by the exhaust gas and by the standard gas. A reduction of the thermal conductivity of the exhaust gas (increasing CO_2 percentage) allows the wires to reach a higher temperature, thus increasing their resistance. As both the wires form part of branches of a Wheatstone bridge an increase in resistance of one wire unbalances the bridge. The amount of electrical unbalance is recorded by a meter of which the scale is calibrated in fuel/air ratio for the Cambridge instrument.

The temperature of the wires depends on :—

(1) Thermal conductivity of the gas surrounding the wire;
(2) Temperature of this gas;
(3) Velocity of this gas;
(4) Temperature of the wall.

To eliminate the second, third and fourth factors the cells containing exhaust gas and standard gas are built in the same block of aluminium or brass, so that the temperature of exhaust gas and standard gas always becomes the same. To guarantee a constant and low gas speed the Lantz-Phelps indicator takes off only a small portion of the exhaust gas under atmospheric pressure, whilst for the

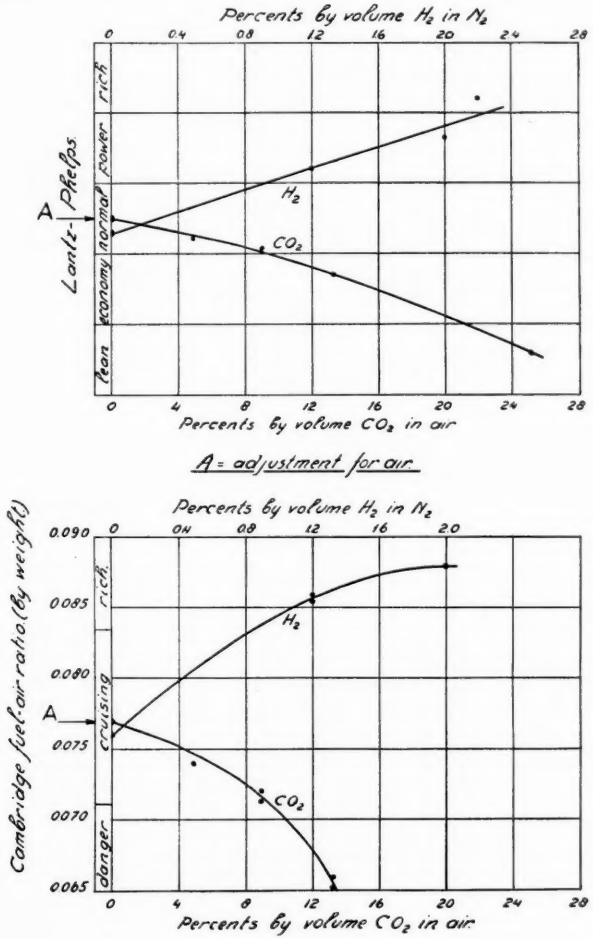

FIG. 3.

Calibration of the Cambridge and the Lantz-Phelps combustion testers.

Cambridge instrument the limits of the allowable gas pressure between inlet and outlet of the apparatus are fixed.

III. CALIBRATION OF THE COMBUSTION INDICATORS OUTSIDE THE ENGINE.

In Fig. 3 the readings of the Cambridge and Lantz-Phelps combustion indicators are plotted against the percentage of CO_2 in air and H_2 in N_2 (N_2 was

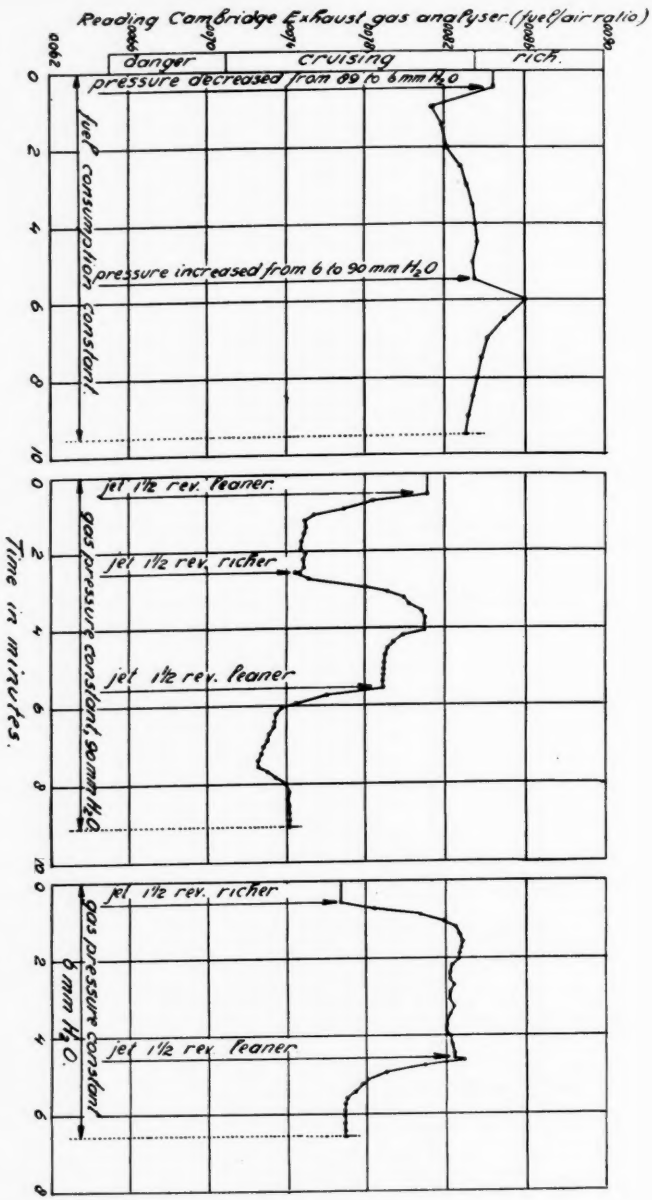
Reading Cambridge Exhaust gas analyser (fuel/air ratio)
danger
cruising
rich.
pressure decreased from 89 to 6 mm H2O
fuel consumption constant.
pressure increased from 6 to 90 mm H2O
jet 1½ rev. leaner.
jet 1½ rev. richer.
jet 1½ rev. leaner.
gas pressure constant, 90 mm H2O.
jet 1½ rev. richer.
jet 1½ rev. leaner.
gas pressure constant 6 mm H2O.
Time in minutes.

FIG. 4.

Determination of the reaction time of the Cambridge "Aero Mixture Indicator" when changing:—

(a) Gas pressure on the cells.

(b) Fuel/air ratio at high and low gas pressure.

Engine: Ford V8, model 48.

Speed: 2,000 r.p.m.

Throttle: Constant.

Ign. Adv.: Constant.

chosen in order to avoid any danger of explosion). It is clearly shown, as may be expected from the data in Table I, that the instruments are much more sensitive to H_2 than to CO_2. Further, it is shown that with air adjustment the use of pure N_2 moves the pointer a little into the lean direction, indicating that the thermal conductivity of N_2 is somewhat lower than that of air. A calculation gives for N_2 a value of 99.3, compared with a value of 100 for air. Landolt and Börnstein give, contrary to this result, equal conductivity for O_2 and N_2.

IV. Engine Tests.

(*a*) *Determination of the sensitivity to changes in gas pressure in the cell and the rapidity of indication of the instrument.*

In Fig. 4 it is shown that the readings of the Cambridge indicator are hardly influenced by changes of the gas pressure between 6-90 mm. water column.

When the gas pressure is increased the needle moves to the rich side. In 4-5 minutes, however, the needle comes back to approximately the original position. Further, it is shown that changes of the fuel/air ratio are shown within one minute.

(*b*) *Effect of short-circuiting a spark plug.*

Fig. 5 shows the effect of short-circuiting one spark plug of an 8-cylinder engine. It is interesting to see that when the engine is running on a " normal " mixture the indicator does not show any change when short-circuiting one spark plug, whereas on a rich mixture the indicator needle moves to a leaner position when one spark plug is short-circuited. The explanation is that the thermal conductivity of air is equal to the thermal conductivity of " normal " exhaust gas and lower than the thermal conductivity of " rich " exhaust gas.

(*c*) *Effect of detonation.*

On the Ricardo E.35 engine a number of tests were carried out in order to investigate the effect of detonation on the indication of the Cambridge instrument. The results are given below.

Table II.

Detonation intensity.	r.p.m.	Brake h.p.	Indication Cambridge Instr. No. 1* upper pointer.	Indication Cambridge Instr. No. 2 lower pointer.	Ignition advance °E.
None	1500	24.2	0.0802	0.0802	29
Slight detonation ...	1490	23.6	0.0815	0.0815	50
None	1510	24.5	0.0802	0.0802	29

* Two Cambridge indicators, intended for a twin-engine airplane, were checked. The two galvanometers were built in one house.

Detonation was caused by advancing the ignition setting. As is shown in the above figures, detonation causes a slight deflection to the rich side of only 0.0013, which corresponds with the figure given by the Wright Aeronautical Corp. in its instruction book for the Cambridge analyser. A test at heavy detonation did not show greater deviations.

The above results show that the deviation caused by detonation is too small to be of practical value. However, the instrument can be useful to *prevent* detonation, as it shows when the mixture is too lean for a given fuel and a given power output. Too lean mixtures facilitate the occurrence of detonation.

(*d*) *Influence of fuel composition, measured in a 4-cylinder Ford engine, Model " A."*

On a 4-cylinder Ford engine, model " A," some preliminary tests were carried out in order to determine the influence of the chemical composition of the fuel

on the reading of the Lantz-Phelps " Combustion Tester." To this end the fuel consumption was varied, keeping the throttle opening constant. Fig. 6 shows the readings of the instrument plotted against fuel consumption per hour, which is proportional to the fuel/air ratio, as speed and throttle opening (which determine the quantity of air) were kept constant during these tests. It is shown

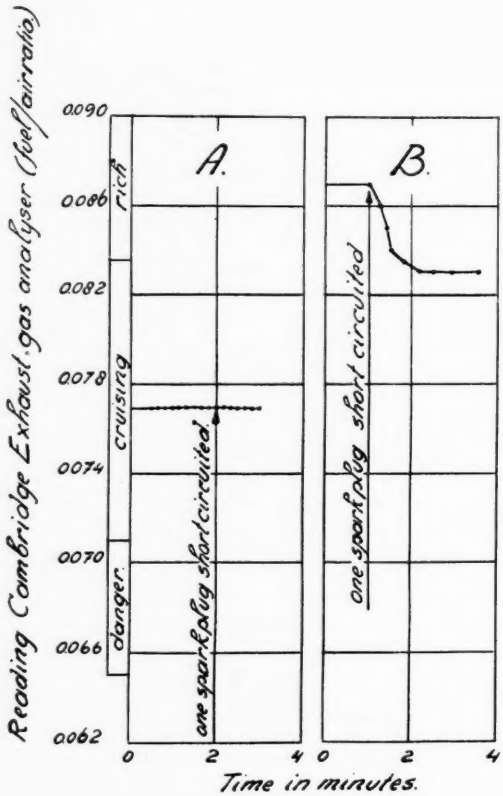

FIG. 5.

Reaction of the Cambridge " Aero Mixture Indicator " when short-circuiting one spark plug:—
(a) The engine running at normal mixture.
(b) The engine running at rich mixture.
Engine: Ford V8, model 48.
Speed: 2,000 r.p.m.
Throttle: Constant.
Ign. Adv.: Constant.

that the curve for benzene lies lower than the curve for petrol, which may be explained by the fact that at equal fuel/air ratio the combustion of benzene gives more CO_2 and les H_2 than the combustion of petrol. Further, it is shown that the curves become flat at a very lean adjustment. The explanation of this has been given already in section I.

(*c*) *Influence of fuel composition measured in a Ford V8 engine, Model 48.*

On a Ford engine, running at different mixture settings, the following readings were taken:—

(*a*) Reading Cambridge indicator.
(*b*) Reading Lantz-Phelps indicator.
(*c*) Fuel consumption.
(*d*) Air consumption (by means of an orifice calibrated by the aerodynamical laboratory of the Technical University of Delft).
(*e*) Power output.
(*f*) Exhaust gas temperature.

Moreover, the percentages CO_2, CO and O_2 were determined for one of the investigated fuels by means of an Orsat analyser.

The tests were carried out on the following fuels:—

Aviation spirit " A."
Aviation spirit " B."
70/30 per cent. by vol. " B "/benzene.
Aviation spirit " C."

The results of the above-mentioned tests are given in Figs. 7, 8, 9 and 10.

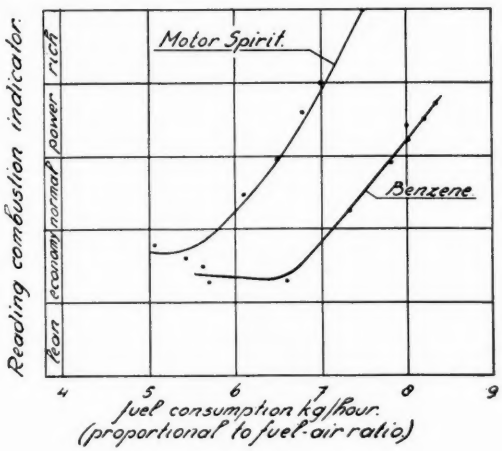

FIG. 6.

Relation between reading Lantz-Phelps " Motor Fuel Combustion Tester " and fuel consumption for different fuels:—
Fuels: (a) Benzene.
(b) Motor spirit.
Engine: Ford, model A.
Speed: 1,700 r.p.m
Throttle: Constant during all tests.
Mixture strength: Variable.

From the combined Fig. 11 it is clearly shown that for the aviation spirit " B " the agreement between the direct and indirect measurement of the fuel/air ratio is satisfactory, whilst for fuels with a higher aromatic content, which means a lower hydrogen-carbon ratio, the instrument gives readings which are too low. When, for instance, 30 per cent. by vol. benzene is added to the aviation spirit " B " containing 13 per cent. aromatics, the resulting blend thus containing 42 per cent. aromatics, the Cambridge instrument indicates from 0.0025 to 0.007

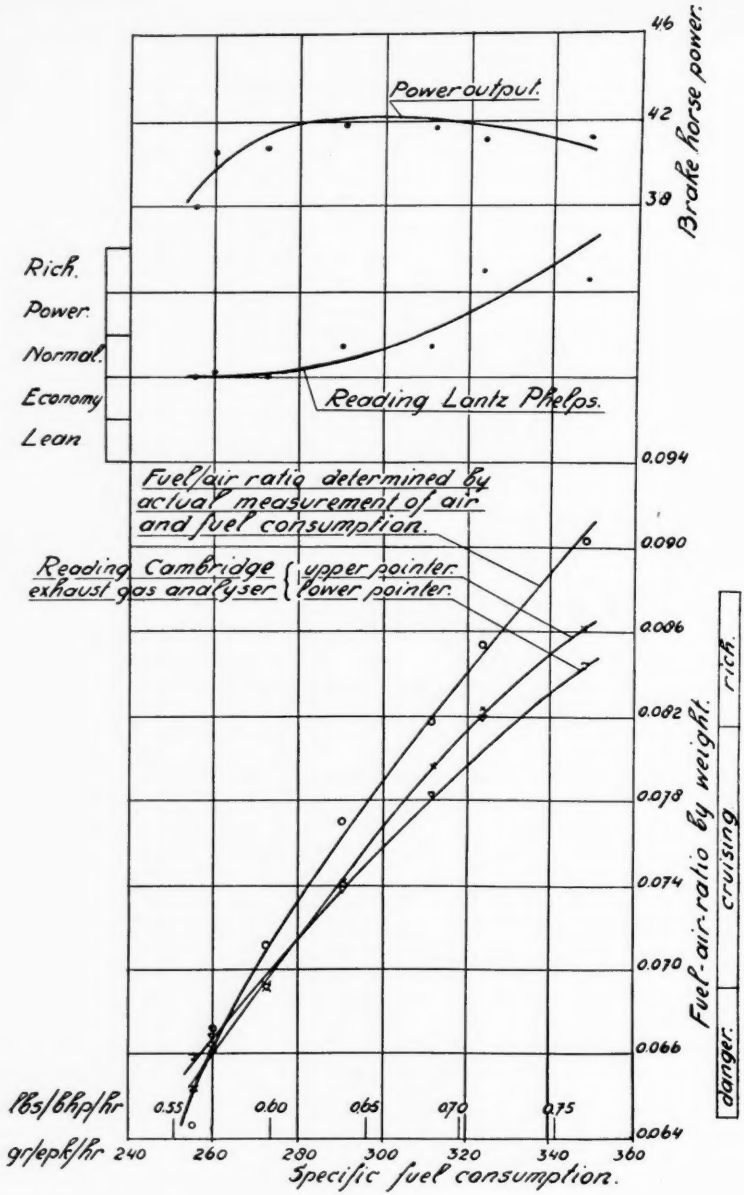

FIG. 7.

Tests on electrical "mixture strength indicators," type Cambridge and Lantz-Phelps:—
Fuel: Aviation spirit "A."
Engine: Ford V8, model 48.
Speed: 2,000 r.p.m.
Mixture strength: Variable.
Throttle: Constant.
Ign. spark advance: Constant.

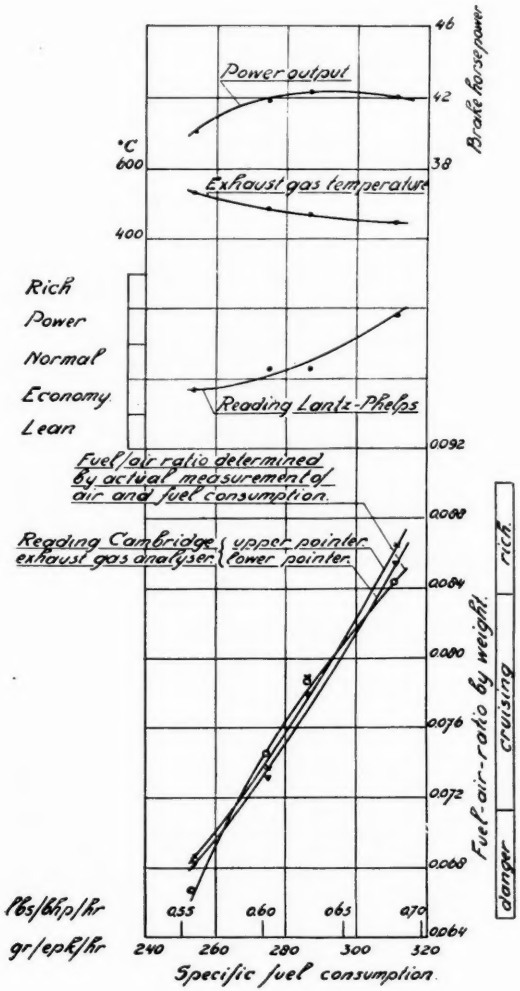

FIG. 8.

Tests on electrical "mixture strength indicators," type Cambridge and Lantz-Phelps:—
Fuel: Aviation spirit "B."
Engine: Ford V8, model 48.
Speed: 2,000 r.p.m.
Mixture strength: Variable.
Throttle: Constant.
Ign. advance: Constant.

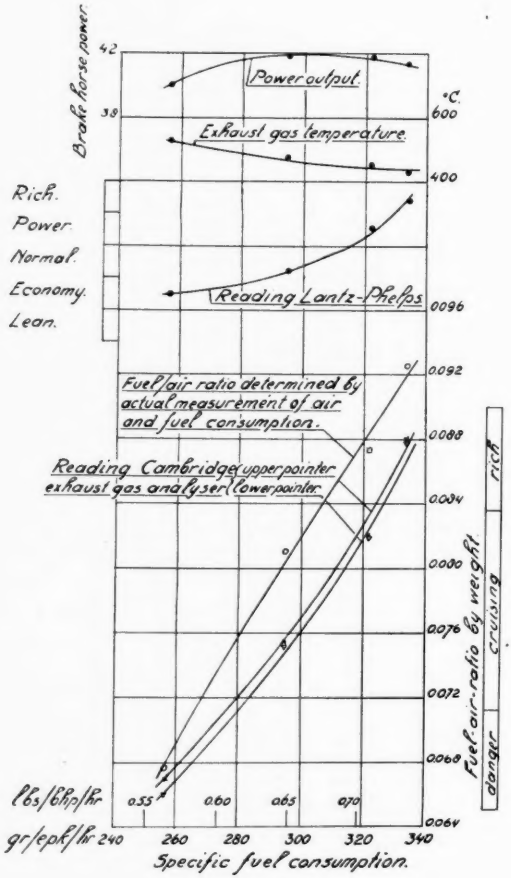

FIG. 9.

Tests on electrical "mixture strength indicators," type Cambridge and Lantz-Phelps:—

Fuel: 70% *by vol. aviation spirit "B."*
30% *by vol. benzene.*

Engine: *Ford V8, model 48.*

Speed: 2,000 *r.p.m.*

Mixture strength: *Variable.*

Throttle: *Constant.*

Ignition advance: *Constant.*

fuel/air ratio too low (*i.e.*, from 3·5 to 8 per cent.). This means that the real fuel/air mixture is richer than the instrument indicates. But at equal air factor a benzene blend requires a richer carburettor setting than a straight petrol. This explains why the deviations between the indications for the aviation spirit "B" and the benzene blend are less (from 2·5 per cent.) when plotted against air

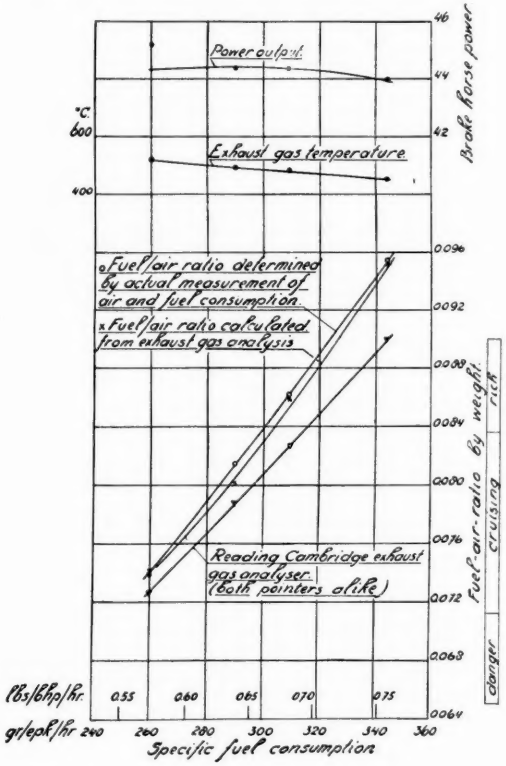

FIG. 10.

Tests on electrical "mixture strength indicators," type Cambridge and Lantz-Phelps:—
Fuel: Aviation spirit "C."
Engine: Ford V8, model 48.
Speed: 2,000 r.p.m.
Mixture strength: Variable.
Throttle: Constant.
Ignition advance: Constant.

factor (*vide* Fig. 12). This may be considered as an advantage, since the ideal combustion tester should not indicate the fuel/air ratio but the air factor, the latter being the direct criterion for the completeness of combustion.

V. Calculation of the Fuel/Air Ratio from the Chemical Composition of the Exhaust Gas Determined by an Orsat Apparatus.

In order to check the figures determined by direct measurement of fuel and air (calibrated orifice) the exhaust gas at various mixture strengths was analysed

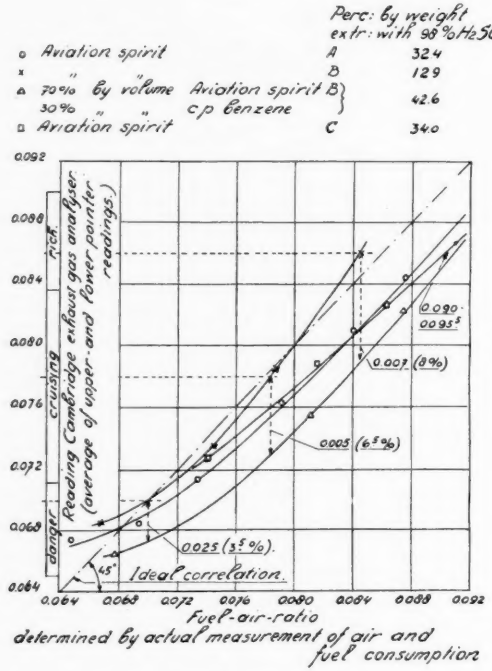

FIG. 11.

Correlation of measured fuel/air ratio and reading of Cambridge "Aero Mixture Indicator" for fuels with different aromatic content.

by means of an Orsat apparatus for the aviation spirit "C." The results are laid down in Table III.

TABLE III.

Composition of exhaust gas. Percentage by volume.				Ratio	Air factor
CO_2	CO	H_2	O_2	H_2:CO	(calculated).
13.0	2.5	1.1	0.3	0.440	1.09
11.4	5.5	2.5	0.4	0.455	1.18
10.5	7.3	3.3	0.3	0.452	1.26
8.3	10.5	4.9	0.1	0.466	1.40

Fuel: Aviation spirit "C."
Hydrogen-carbon ratio 0.158.

From the various figures giving the content of CO_2, CO, H_2 and O_2 the air factor was calculated. The fuel/air ratios thus obtained agreed fairly well with the fuel/air ratios determined by direct measurement (*vide* Fig. 10).

In Fig. 13 the percentages of the various components in the exhaust gas are plotted against the air factor. It is shown that at increasing air factor the H_2 and CO content gradually increases. With reference to the water gas equilibrium mentioned under the heading "Principles," it is shown that here a linear relation exists between the percentages H_2 and CO. For the fuel considered the equation is $H_2 = 0.46$ CO (*vide* Table III). This equation corresponds fairly well with the equation $H_2 = 0.50$ CO given by Gerrish and Tessmann (Ref. 2) as an average of several samples.

Although for some years the Delft Laboratory has occupied itself with the investigation of exhaust gas analysers, we have to express our great gratitude to the K.L.M. (Royal Dutch Airlines) who have drawn our attention to the "Cambridge (N.Y.) Aero Mixture Indicator." We are also very grateful to Mr. G. Lam, chief of the instrument department of the K.L.M., who placed an apparatus at our disposal for experimental purposes and gave us most valuable assistance.

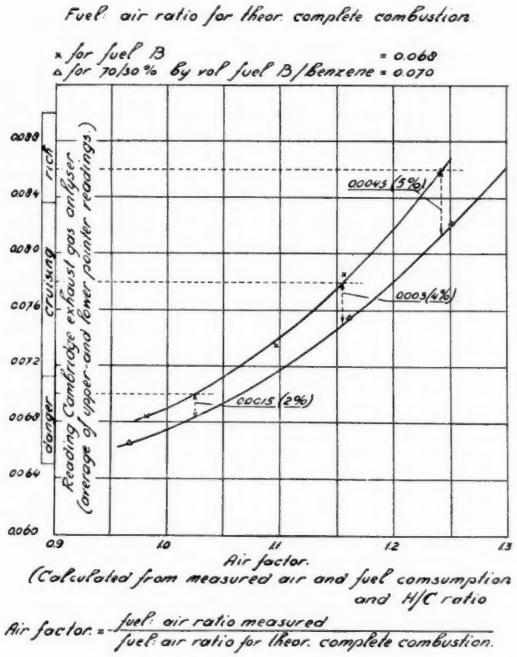

FIG. 12.

Relation between reading Cambridge "Aero Mixture Indicator" and air factor for fuels of different chemical composition (vide also Fig. 11).

In conclusion the authors wish to thank Dr. H. van Driel, doctor of physics, and Baron W. J. van Heeckeren, research engineer, of the Delft Laboratory, for their most valuable co-operation in preparing this paper.

CONCLUSIONS.

The tests described in this paper prove that electrical indications for showing mixture strength may be of practical value to aircraft pilots.

The indicators investigated, the Cambridge (N.Y.) aircraft type and the Lantz-Phelps automobile type, measure the thermal conductivity of the exhaust gas. As the thermal conductivity of H_2 is much higher than the thermal conductivity of CO_2 is lower than that of the other components present in the exhaust gas, the indicators mainly respond to the H_2 and the CO_2 content in the exhaust gas.

The following facts explain why for a given fuel the fuel/air ratio can be deduced from the thermal conductivity of the exhaust gas:—

(*a*) For mixtures as used in practice the percentage of CH_4 and O_2 in the exhaust gas is small and may be considered as constant (approx. 0.2-0.3 per cent.) (*vide* List of References (3)).

(*b*) A fixed relation appears to exist between the percentages CO, CO_2, H_2 and H_2O, which may be ascribed to the water gas equilibrium according to d'Alleva and Lovell (Gen. Motors) (*vide* List of References (4)).

The readings of electric indicators for showing mixture strength depend on the chemical composition of the fuel under test. Upon the addition, for instance, of 30 per cent. aromatics to a fuel, the Cambridge instrument indicated from 0.0025-0.007 fuel/air ratio lower (*i.e.*, from 3.5-8 per cent.). This means that the real fuel/air ratio is richer than the instrument indicates. But with equal air factor a benzene blend requires a richer carburettor setting than a straight petrol. This explains why the deviations between the indications for the aforementioned fuel and the benzene blend are lower (from 2-5 per cent.) when plotted against air factor than when plotted against fuel/air ratio.

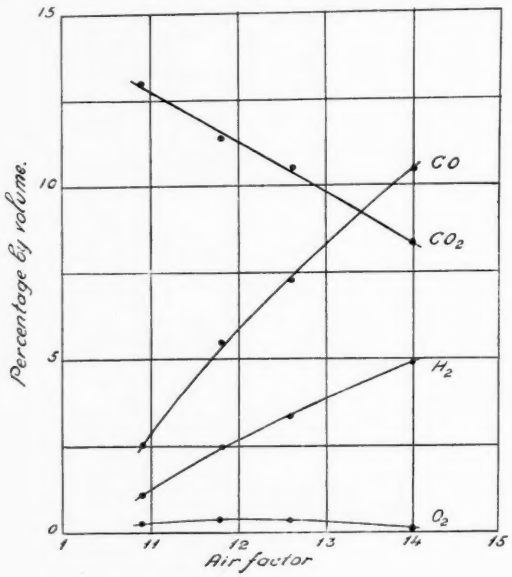

FIG. 13.

Composition of exhaust gas as a function of air factor:—
Fuel: Aviation spirit "C."
Engine: Ford V8, model 48.
Speed: 2,000 r.p.m.
Mixture strength: Variable.
Throttle: Constant.
Ignition advance: Constant.

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APPROXIMATE METHODS FOR FINDING FREQUENCIES OF VIBRATION.*

By Capt. J. Morris, B.A.

Introduction.

The rapid progress made in mechanical engineering during the present century has brought many troublesome problems in its wake. One of the most serious of these troubles arises from resonant and such like vibration. It has, therefore, become increasingly necessary for a designer to take account of vibration. A powerful instrument for this purpose was provided by the late Lord Rayleigh, whose method for finding an approximation to the fundamental frequency of vibration of an elastic system is fairly well known. In this paper an attempt is made *inter alia* to explain Rayleigh's Principle and to clarify, so far as the author is able to do so, the basis of the principle. Other devices for ascertaining approximate frequencies are also given and an appendix has been added on forced vibration experiments.

§1. Rayleigh's Principle.

Rayleigh's Principle is based on the proposition that in the fundamental mode of vibration of an elastic system, the distribution of kinetic and potential energies is such as to make the frequency a minimum.† This proposition appears to be part of a general theorem relating to all the frequencies of a system as will be obvious from what follows.

§1.1. Proof of the Principle for a Simple Case.

Consider the case of a light elastic rod supported horizontally in any supports.

Let two masses m_1, m_2, be concentrated at points (designated 1, 2) of the rod. Let these masses be in free lateral vibration. At time t let Y_1, Y_2, be the displacements of the masses from the initial elastic line of the rod when at rest. If the motion be simple harmonic of frequency $k/2\pi$ then at the instant t

$$Y_1 = A_1 \cos(kt + \epsilon),$$

$$\text{and } Y_2 = A_2 \cos(kt + \epsilon),$$

where A_1, A_2 are amplitudes and ϵ is an epoch angle.

The inertia forces of the masses will be $m_1k^2Y_1$, $m_2k^2Y_2$, and the displacements Y_1, Y_2, may be regarded as due to these. Hence

$$m_1k^2Y_1 = \eta_{11}Y_1 + \eta_{12}Y_2, \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\text{and } m_2k^2Y_2 = \eta_{12}Y_1 + \eta_{22}Y_2; \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where η_{11}, η_{12}, η_{22}, are elastic coefficients of the rod relating to the points 1 and 2.

We thus have

$$m_1k^2A_1 = \eta_{11}A_1 + \eta_{12}A_2, \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\text{and } m_2k^2A_2 = \eta_{12}A_1 + \eta_{22}A_2. \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Multiplying (3) by A_1 and (4) by A_2 and adding we find that

$$k^2 = (\eta_{11}A_1^2 + 2\eta_{12}A_1A_2 + \eta_{22}A_2^2)/(m_1A_1^2 + m_2A_2^2). \quad . \quad . \quad (5)$$

* Crown copyright reserved.

† See "Rayleigh's Principle," by G. Temple and W. G. Bickley (Oxford University Press).

But equations (3) and (4) are those which would be obtained in finding the values for which k^2 expressed as the homogeneous function of A_1, A_2, on the right hand side of (5) is stationary.

Let now

$$V = \tfrac{1}{2}(\eta_{11}A_1^2 + 2\eta_{12}A_1A_2 + \eta_{22}A_2^2),$$
$$\text{and } W = \tfrac{1}{2}(m_1A_1^2 + m_2A_2^2);$$
$$\text{then } k^2 = V/W$$

where V is actually the amplitude of the potential energy of the rod; k^2W is the amplitude of the work done by the inertia forces on the rod; and $V = k^2W$.

Now

$$\partial k^2/\partial A_1 = (1/W)(\partial V/\partial A_1) - (V/W^2)(\partial W/\partial A_1)$$
$$= (1/W)[(\partial V/\partial A_1) - (k^2\partial W/\partial A_1)].$$

Also we find that

$$\partial^2 k^2/\partial A_1^2 = (1/W)[(\partial^2 V/\partial A_1^2) - (k^2\partial^2 W/\partial A_1^2)]$$
$$-(2/W^2)(\partial W/\partial A_1)[(\partial V/\partial A_1) - (k^2\partial W/\partial A_1)].$$

Thus for the particular example, equations (3) and (4) may be written

$$\partial k^2/\partial A_1 = 0,$$
$$\text{and } \partial k^2/\partial A_2 = 0;$$

which are the conditions for a stationary value of k^2 expressed as a function of the parameters A_1, A_2.

Also

$$\partial^2 k^2/\partial A_1^2 = (1/W)(\eta_{11} - m_1k^2),$$
$$\partial^2 k^2/\partial A_2^2 = (1/W)(\eta_{22} - m_2k^2),$$
$$\text{and } \partial^2 k^2/\partial A_1\partial A_2 = (1/W)\eta_{12}.$$

Now the two appropriate values of k^2 are found from the equation

$$(\eta_{11} - m_1k^2)(\eta_{22} - m_2k^2) - \eta_{12}^2 = 0.$$

Representing the left hand side of this equation by $f(k^2)$ we have

$$f(0) = \eta_{11}\eta_{22} - \eta_{12}^2$$

which may be shown to be always positive,

$$f(\eta_{11}/m_1) = -\eta_{12}^2$$

which is negative,

$$f(\eta_{22}/m_2) = -\eta_{12}^2$$

which is likewise negative, and $f(+\infty)$ is always positive.

Hence the values of $k^2 = \eta_{11}/m_1$, η_{22}/m_2, are between the two roots in k^2 (which may be shown to be real and positive).

Thus for the lower root in k^2 both

$$\partial^2 k^2/\partial A_1^2 \text{ and } \partial^2 k^2/\partial A_2^2 \text{ are positive}$$

and for the higher root both are negative, while

$$(\partial^2 k^2/\partial A_1^2)(\partial^2 k^2/\partial A_2^2) - (\partial^2 k^2/\partial A_1\partial A_2)^2 = 0 \text{ for both roots.}$$

Hence in this particular case the k^2 for the fundamental is a minimum when expressed as an appropriate energy function of the parameters A_1, A_2, while the k^2 for the higher value or overtone is a maximum.

§ 1.2. The General Case for any Number of Finite Masses.

To prove the general case it will suffice to deal with the case of three loads. Proceeding as in § 1.1, the appropriate equation for k^2 will be found to be

$$\Delta_3 = \begin{vmatrix} \eta_{11} - m_1k^2, & \eta_{12}, & \eta_{13} \\ \eta_{12}, & \eta_{22} - m_2k^2, & \eta_{23} \\ \eta_{13}, & \eta_{23}, & \eta_{33} - m_3k^2 \end{vmatrix} = 0.$$

$$\text{Let } \Delta_2 = \begin{vmatrix} \eta_{11} - m_1k^2, & \eta_{12} \\ \eta_{12}, & \eta_{22} - m_2k^2 \end{vmatrix}$$

$$\text{and } \Delta_1 = \eta_{11} - m_1k^2.$$

Then it may be shown that the root of the equation $\Delta_1 = 0$ in k^2 is between the two roots of the equation $\Delta_2 = 0$ in k^2, and that these latter roots are between the roots of the equation $\Delta_3 = 0$ in k^2.

Hence the value $k^2 = \eta_{11}/m_1$ must be greater than the lowest root in k^2 of $\Delta_3 = 0$. Similarly the values $k^2 = \eta_{22}/m_2$, η_{33}/m_3, exceed this lowest root.

The foregoing is evidently general for any number of masses. Hence, having regard to all the necessary conditions, we conclude that for an elastic system of any number of finite masses the fundamental k^2 will be a minimum when expressed as an appropriate energy function of the amplitudes of vibration. It has not been proved that no values of k^2 other than the fundamental can be a minimum, but it appears that above a certain value the k^2's will be maxima. What one would expect is that the respective totals of maxima and minima should be equal or differ by unity with the possibility that some intermediate values may be merely stationary.

§1.3. Examples of the Use of the Principle.

By using the principle somewhat on the lines of Ritz,* we may readily obtain very close approximations to fundamental frequencies and, if required, higher frequencies.

Take for example the case of a uniform rod encastré at one end and rotating about an axis in the plane of vibration and perpendicular to the elastic axis as in Fig. 1.

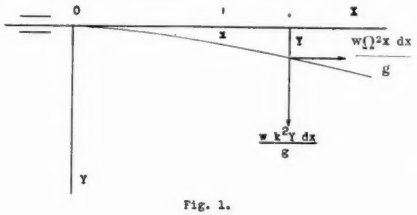

Fig. 1.

Let

$$Y = a_2 x^2 + a_3\ (x^3/l)\dagger$$

be the shape of the curve assumed where a_2, a_3, are the amplitudes of harmonic functions of the time. What we are really doing by this assumption is to prescribe the amplitude at any point in terms of two parameters.

The boundary conditions satisfied are

$$x = 0,\ Y = 0,\ dY/dx = 0.$$

The potential energy stored up in the rod will be

$$\tfrac{1}{2}\int_0^l EI\ (d^2Y^2/dx^2)^2\ dx = 2\ EIl\ (a_2^2 + 3\ a_2 a_3 + 3\ a_3^2).$$

The work done by the lateral inertia forces will be

$$\tfrac{1}{2}\int_0^l (wk^2Y^2/g)\ dx = (wk^2/2\ g)\ l^5\ (a_2^2/5 + a_2 a_3/3 + a_3^2/7).$$

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* W. Ritz, *Journ. f.d. reine und angewandte Math.* CXXXV, 1 (1908); *Gott. Nach.* 236 (1908); *Ann. d. Physik*, XXVIII, 737 (1900).

† In the usual application of Rayleigh's method for this example the corresponding function of the same degree would be

$$Y = a\{x^2 - (x^3/3l)\}$$

which would satisfy the boundary conditions

$$x = 0,\ Y = 0,\ dY/dx = 0;\ x = l,\ d^2Y/dx^2 = 0.$$

This would, however, evidently give a less accurate fundamental than that obtained by the method given.

The work done by the centrifugal forces will be

$$-\tfrac{1}{2}\int_0^l (w x \Omega^2/g)\left\{\int_0^x (dY/dx)^2\,dx\right\}dx$$

$$= -(w\Omega^2/2g)\,l^5\left[(4a_2^2/15)+\tfrac{1}{2}a_2a_3+(9a_3^2/35)\right].$$

Hence

$$2EIl\,(a_2^2+3a_2a_3+3a_3^2)+(w\Omega^2/2g)\,l^5\left[(4a_2^2/15)+\tfrac{1}{2}a_2a_3+(9a_3^2/35)\right]$$
$$=(wk^2/2g)\,l^5\left[(a_2^2/5)+(a_2a_3/3)+(a_3^2/7)\right].$$

Let $\lambda = 4EIg/wl^4$.

Then

$$k^2=\left[\{\lambda+(4\Omega^2/15)\}a_2^2+\{3\lambda+(\Omega^2/2)\}a_2a_3\right.$$
$$\left.+\{3\lambda+(9\Omega^2/35)\}a_3^2\right]/\left[(a_2^2/5)+(a_2a_3/3)+(a_3^2/7)\right].$$

We next find the stationary values of k^2 regarding a_2, a_3, as variables. These are readily obtained in this case by expressing the condition that the above equation regarded as a quadratic in a_2/a_3 or a_3/a_2 should have equal roots.

We thus obtain the equation in k^2

$$4\left[(k^2/5)-\{\lambda+(4\Omega^2/15)\}\right]\left[(k^2/7)-\{3\lambda+(9\Omega^2/35)\}\right]$$
$$-\left[(k^2/3)-\{3\lambda+(\Omega^2/2)\}\right]^2=0$$

or

$$k^4-(306\lambda+7.8\Omega^2)k^2+(945\lambda^2+387\lambda\Omega^2+7.75\Omega^4)=0;$$

from which we find

$$\left.\begin{matrix}k_1^2\\k_2^2\end{matrix}\right\}=\mp\sqrt{(22464\lambda^2+806.4\lambda\Omega^2+7.56\Omega^4)}+153\lambda+3.9\Omega^2.$$

If $\Omega^2=0$

$$k_1^2=153\lambda-149.88\lambda$$
$$=3.12\lambda$$
$$=12.48\,EIg/wl^4.$$

The more accurate value is

$$k_1^2=12.36\,EIg/wl^4;$$

so that the error in the approximation for k_1 is about $\frac{1}{2}$ per cent.

Let $\Omega^2/28\lambda$ be small, *i.e.*, Ω^2 is small compared with $9k_1^2$; then

$$k_1^2=153\lambda+3.9\Omega^2-149.88\lambda\,(1+\Omega^2/56\lambda)\text{ app.}$$
$$=3.12\lambda+(3.9-2.68)\Omega^2$$
$$=(k_1^2)_{\Omega^2=0}+1.22\Omega^2;$$
$$\text{or } k^2=k_0^2+1.22\Omega^2.$$

In this case we find that the other root in k^2 is not a good approximation to the corresponding value for the actual first overtone, the reason being apparently that very few of the boundary conditions are satisfied. Indeed at the free end none are so satisfied. Where, however, the boundary conditions are better satisfied then the approximation for the overtone is correspondingly closer.

Take for example the case of a body encastré at one end, the centroids of whose cross sections are on a straight line and whose area and flexural moment of inertia at any point x from the origin are given by

$$A_x=0.69\,ct_m\{1-(x/l)\}^{3/2}$$
$$I_x=0.05\,ct_m^3\{1-(x/l)\}^{7/2}$$

where c, t_m are constant and l is the length of body. Such a body is a rough representation of an airscrew.

Proceeding on the lines of the previous example and assuming the same type of elastic curve, viz. :—

$$Y=a_2x^2+a_3(x^3/l)$$

we find potential energy stored up in body will be

$$\tfrac{1}{2}\int_0^l EI_x\,(d^2Y/dx^2)^2\,dx$$

$$=\tfrac{1}{2}\,E\times 0.05\,ct_m{}^3\int_0^l \{\,1-(x/l)\,\}^{7/2}\,[4\,a_2{}^2+24\,a_2a_3\,(x/l)+36\,a_3{}^2\,(x^2/l^2)]\,dx.$$

The work done by the lateral inertia forces will be

$$\tfrac{1}{2}\int_0^l (\rho/g)\,A_xk^2Y^2dx$$

$$=\tfrac{1}{2}\,(\rho/g)\,k^2\times 0.69\,ct_m\int_0^l \{\,1-(x/l)\,\}^{3/2}\,[a_2{}^2x^4+2\,a_2a_3\,(x^5/l)+a_3{}^2\,(x^6/l^2)]\,dx.$$

The work done by the centrifugal forces will be

$$-\tfrac{1}{2}\int_0^l (\rho/g)\,A_xx\Omega^2\,\{\int_0^x (dY/dx)^2\,dx\,\}\,dx$$

$$=-\tfrac{1}{2}\,(\rho/g)\,\Omega^2\times 0.69\,ct_m\int_0^l \{\,1-(x/l)\,\}^{3/2}\,[4\,a_2{}^2\,(x^4/3)$$

$$+3\,a_2a_3\,(x^5/l)+9\,a_3{}^2\,(x^6/5l^2)]\,dx.$$

On evaluation of the integrals the energy equation therefore becomes

$$\lambda\,[a_2{}^2+(12\,a_2a_3/11)+(72\,a_2{}^2/143)]$$
$$=k^2\,[a_2{}^2+(4\,a_2a_3/3)+(8\,a_3{}^2/17)]-\Omega^2\,[(4\,a_2{}^2/3)+2\,a_2a_3+(72\,a_3{}^2/85)]$$

where $\lambda=(Eg\times 0.05\times 5\times 7\times 11\times 13\,t_m{}^2)/(\rho l^4\times 0.69\times 96)$

and ρ is the density of the material.

For k^2 to be stationary we obtain the equation

$$4\,[k^2-\lambda-(4\,\Omega^2/3)]\,[(8\,k^2/17)-(72/143\,\lambda)-(72/85\,\Omega^2)]$$
$$=[(4\,k^2/3)-(12\,\lambda/11)-2\,\Omega^2]^2$$

which may be written

$$k^4-(9.438\,\lambda+5.403\,\Omega^2)\,k^2$$
$$+(7.880\,\lambda^2+16.342\,\lambda\Omega^2+4.953\,\Omega^4)=0.$$

Thus $\left.\begin{matrix}k_1{}^2\\k_2{}^2\end{matrix}\right\}=\mp\sqrt{(14.389\,\lambda^2+9.150\,\lambda\Omega^2+2.342\,\Omega^4)}+4.719\,\lambda+2.701\,\Omega^2.$

If $\Omega^2=0$ we find

$$k_1{}^2=0.926\,\lambda$$
$$\text{and } k_2{}^2=8.512\,\lambda.$$

Using the value for λ we find that

$$k_1/2\,\pi=0.298\,(t_m/l^2)\sqrt{(Eg/\rho)}$$

which agrees exactly to the same order of accuracy with the value obtained by solving the appropriate differential equation by series (see §3).

Also

$$k_2:k_1=3.03.$$

The ratio obtained by the series solution is

$$k_2:k_1=2.62.$$

Hence so far as the fundamental is concerned we have obtained a sufficiently accurate solution.

Taking account of Ω^2 we obtain the following where

$$(k_o^2)_1 = 0.926\ \lambda$$
$$(k_o^2)_2 = 8.512\ \lambda$$
$$k_1^2 = (k_o^2)_1 + \alpha_1\Omega^2$$
$$k_2^2 = (k_o^2)_2 + \alpha_2\Omega^2$$
$$\Omega^2 = r\lambda.$$

r	α_1	α_2
0	0	0
1	1.41	3.99
2	1.36	4.04
3	1.33	4.06
4	1.30	4.10
5	1.28	4.12
6	1.27	4.12
7	1.26	4.14
10	1.24	4.16
20	1.21	4.19
100	1.18	4.22

For practical purposes Ω^2 will be of the order k_1^2; so that the appropriate values of α_1 and α_2 will be 1.4 and 4.0 respectively.

The value for the fundamental is likely to be very close to the actual value while that for the overtone is likely to be fairly close.

The reason we obtain a closer approximation to the overtone in this case is because owing to the taper more end conditions are satisfied. Thus at the free end

$$EI_x d^2Y/dx^2 \text{ and } (d/dx)(EI_x d^2Y/dx^2)$$

are both zero.

§1.4. Case of "Free-Free" Vibration.

So far we have dealt principally with the case of a loaded rod encastré at one end and free at the other end. We have also to consider cases where the rod may be entirely free or where it may be hinged at one end and free at the other. Let us consider in this connection the case illustrated in Fig. 2.

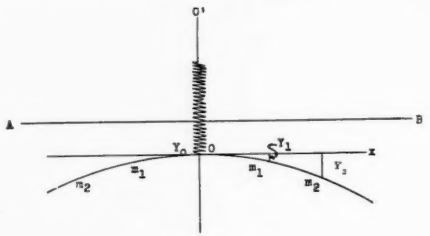

Fig. 2.

$m_2m_1m_1m_2$ is a light rod carrying two pairs of concentrated masses m_1, m_2, the whole system being symmetrical with regard to the axis OY. $O'O$ is a spring and the system is supposed to execute vibrations of the type indicated by the diagram. Let AB be the position of rest of the system and at time t let Y_o be the displacement of O from this mean position. Let Ox be parallel to AB and at time t let Y_1, Y_2 be the displacements of m_1, m_2 relative to Ox.

Regarding Om_1m_2 as a cantilever we have the following elastic equations:—

$$m_1k^2(Y_1 + Y_o) = \eta_{11}Y_1 + \eta_{12}Y_2 \quad . \quad . \quad . \quad . \quad (1)$$
$$m_2k^2(Y_2 + Y_o) = \eta_{12}Y_1 + \eta_{22}Y_2 \quad . \quad . \quad . \quad . \quad (2)$$

where the left hand side represents inertia forces and the right hand side represents corresponding restoring forces due to the bending of the cantilever.

Also we have for the system

$$m_1k^2\,(Y_1+Y_o)+m_2k^2\,(Y_2+Y_o)=\xi_{11}Y_o \qquad . \quad . \quad . \quad (3)$$

where $2\,\xi_{11}$ is the elastic coefficient of the spring.

Let

$$V=\tfrac{1}{2}\,(\eta_{11}Y_1{}^2+2\,\eta_{12}Y_1Y_2+\eta_{22}Y_2{}^2)+\tfrac{1}{2}\,\xi_{11}Y_o{}^2$$

and

$$W=\tfrac{1}{2}\,[m_1\,(Y_1+Y_o)^2+m_2\,(Y_2+Y_o)^2].$$

V thus represents the sum of the energy stored up in one half the system due to bending and half the energy stored up in the spring; while k^2W represents the work done by the inertia forces on one half of the system.

If A_o, A_1, A_2 are the amplitudes of Y_o, Y_1, Y_2, then we may write

$$k^2=V/W$$

where V and W are expressed as the appropriate functions of the amplitudes.

The amplitude equations corresponding to (1), (2) and (3) may then be derived as follows:—

$$\partial k^2/\partial A_1=0$$
$$\partial k^2/\partial A_2=0$$
$$\partial k^2/\partial A_o=0.$$

Also we find

$$\partial^2k^2/\partial A_1{}^2=(1/W)\,(\eta_{11}-m_1k^2)$$
$$\partial^2k^2/\partial A_2{}^2=(1/W)\,(\eta_{22}-m_2k^2)$$
$$\partial^2k^2/\partial A_o{}^2=(1/W)\,[\xi_{11}-(m_1+m_2)\,k^2].$$

From equations (1), (2) and (3) we obtain the determinantal equation in k^2

$$\begin{vmatrix} \eta_{11}-m_1k^2, & \eta_{12}, & -m_1k^2 \\ \eta_{12}, & \eta_{22}-m_2k^2, & -m_2k^2 \\ -m_1k^2, & -m_2k^2, & \xi_{11}-(m_1+m_2)\,k^2 \end{vmatrix}=0$$

This equation is apparently a cubic in k^2, but actually one of the roots will be infinite as the coefficient of k^6 is zero. Hence we have two finite roots in k^2.

It may be shown as in §1.1 and §1.2 that for the lower or fundamental value k^2 will be a minimum for all possible values of the parameters A_o, A_1, A_2. So far as the second root is concerned it appears that it may be a maximum or minimum according to the values of the quantities involved.

The above determinantal equation in k^2 may be written

$$\begin{vmatrix} \eta_{11}-m_1k^2, & \eta_{12}, & \eta_{11}+\eta_{12} \\ \eta_{12}, & \eta_{22}-m_2k^2, & \eta_{12}+\eta_{22} \\ \eta_{11}+\eta_{12}, & \eta_{12}+\eta_{22}, & \eta_{11}+2\,\eta_{12}+\eta_{22}+\xi_{11} \end{vmatrix}=0$$

The constant term of this equation may be shown to reduce to

$$\xi_{11}\,(\eta_{11}\eta_{22}-\eta_{12}{}^2)$$

and this will clearly vanish when $\xi_{11}=0$, *i.e.*, when the spring becomes infinitely weak.

In these circumstances the fundamental frequency of the system vanishes and the overtone becomes the fundamental frequency in the "free-free" vibration of the system.

When $\xi_{11}=0$ the equation in k^2 may be written

$$\begin{aligned}&(\eta_{11}+2\,\eta_{12}+\eta_{22})\,[(\eta_{11}-m_1k^2)\,(\eta_{22}-m_2k^2)-\eta_{12}{}^2]\\&-(\eta_{12}+\eta_{22})^2\,(\eta_{11}-m_1k^2)-(\eta_{11}+\eta_{12})^2\,(\eta_{22}-m_2k^2)\\&+2\,\eta_{12}\,(\eta_{11}+\eta_{12})\,(\eta_{12}+\eta_{22})=0\end{aligned}$$

of which the constant term will be found to vanish.

If we put $\eta_{11}=m_1k^2$ in this equation the left hand side becomes after reduction

$$(\eta_{11}/m_1)\left[m_2(\eta_{11}+\eta_{12})^2-m_1(\eta_{11}\eta_{22}-\eta_{12}^2)\right].$$

Similarly if we put $\eta_{22}=m_2k^2$ the left hand side becomes

$$(\eta_{22}/m_2)\left[m_1(\eta_{12}+\eta_{22})^2-m_2(\eta_{11}\eta_{22}-\eta_{12}^2)\right].$$

Now η_{11}, η_{22} and $\eta_{11}\eta_{22}-\eta_{12}^2$ are all positive. Hence the two foregoing expressions may be positive or negative according to the values of the quantities involved.

It would thus appear in the "free-free" case that the fundamental value of k^2 as the appropriate function of A_0, A_1, A_2, although stationary, is not a minimum. It may be either a maximum or merely stationary.

We have therefore to exercise care when applying Rayleigh's Principle to cases of this kind. As to whether the maximum or minimum values are applicable, this may have to be decided from other considerations.

We next consider the case illustrated in Fig. 3.

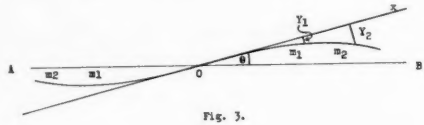

Fig. 3.

In this case the vibration is torsional about o.

Let $BOx=\theta$, $Om_1=a_1$, $Om_2=a_2$.

The appropriate equations are now

$$m_1k^2(Y_1-a_1\theta)=\eta_{11}Y_1+\eta_{12}Y_2$$
$$m_2k^2(Y_2-a_2\theta)=\eta_{12}Y_1+\eta_{22}Y_2$$
$$m_1k^2a_1(Y_1-a_1\theta)+m_2k^2a_2(Y_2-a_2\theta)=-c_{11}\theta$$

where $2c_{11}$ is the stiffness of the spring at o.

Using amplitudes we have

$$V=\tfrac{1}{2}\left[\eta_{11}A_1^2+2\eta_{12}A_1A_2+\eta_{22}A_2^2\right]+\tfrac{1}{2}c_{11}\alpha^2$$
$$W=\tfrac{1}{2}\left[m_1(A_1-a_1\alpha)^2+m_2(A_2-a_2\alpha)^2\right]$$
$$k^2=V/W.$$

The treatment then proceeds as in the previous case.

The appropriate equation for k^2 is

$$\begin{vmatrix} \eta_{11}-m_1k^2, & \eta_{12}, & a_1\eta_{11}+a_2\eta_{12} \\ \eta_{12}, & \eta_{22}-m_2k^2, & a_1\eta_{12}+a_2\eta_{22} \\ a_1\eta_{11}+a_2\eta_{12}, & a_1\eta_{12}+a_2\eta_{22}, & a_1^2\eta_{11}+2a_1a_2\eta_{12}+a_2^2\eta_{22}+c_{11} \end{vmatrix}=0$$

As in the previous case the constant term of the equation is

$$c_{11}(\eta_{11}\eta_{22}-\eta_{12}^2)$$

and this vanishes when $c_{11}=0$.

If $c_{11}=0$ and $\eta_{11}=m_1k^2$ then the left hand side of the above determinantal equation becomes

$$(\eta_{11}/m_1)\left[m_2(a_1\eta_{11}+a_2\eta_{12})^2-m_1a_1^2(\eta_{11}\eta_{22}-\eta_{12}^2)\right]$$

similarly if $\eta_{22}=m_2k^2$ it becomes

$$(\eta_{22}/m_2)\left[m_1(a_1\eta_{12}+a_2\eta_{22})^2-m_2a_2^2(\eta_{11}\eta_{22}-\eta_{12}^2)\right].$$

These expressions may be positive or negative according to the values of the quantities involved.

As an example of this kind of vibration let Om_1m_2 in Fig. 3 be a uniform rod hinged at O, but otherwise free to vibrate in the plane xoY.

Let w = weight per unit length of the rod.
l = length of the rod.
I = flexural moment of inertia of the section.
E = Young's Modulus of the material.
g = acceleration due to gravity.

The equation of motion of the rod in free vibration and without any imposed rotation will be

$$EI\partial^4 y/\partial x^4 = -(w/g)\,\partial^2 y/\partial t^2.$$

Assume a solution of the form

$$y = Y\cos(kt+\epsilon)$$

where Y is a function of x only, $k/2\pi$ is a frequency, and ϵ is an epoch angle.

We obtain on substitution the equation

$$EId^4Y/dx^4 = (w/g)\,k^2Y$$

or

$$d^4Y/dx^4 = m^4Y$$

where

$$m^4 = wk^2/EIg.$$

The solution of this equation having regard to the end conditions is found to be

$$Y = a_1\sin mx - a_2\sinh mx$$

where $\tan ml = \tanh ml$ and a_1, a_2 are constants such that

$$-a_1\sin ml = a_2\sinh ml.$$

The roots of the above equation in ml are found to be approximately

$$ml = 5\pi/4,\ 9\pi/4,\ 13\pi/4.\ \ldots$$

Taking the fundamental

$$ml = 5\pi/4.$$
$$\therefore\ m^4l^4 = (5\pi/4)^4$$

from which we find

$$k/2\pi = (2.45/l^2)\sqrt{(EIg/w)}.$$

Suppose now the system is rotating about the axis OY with constant angular velocity Ω, then we may assume an elastic curve of the form

$$Y = a_1\sin mx - a_2\sinh mx$$

where $ml = 5\pi/4$ and a_1, a_2 are arbitrary parameters.

The work done by the bending moments is found to be

$$\tfrac{1}{2}EIm^4\,[a_1^2\{\tfrac{1}{2}-(\sin 2\,ml/4\,ml)\}\,l + (a_1a_2/m)(\cosh ml\sin ml-\sinh ml\cos ml) + a_2^2\{(\sinh 2\,ml/4\,ml)-\tfrac{1}{2}\}\,l].$$

The work done by the lateral inertia forces is found to be

$$\tfrac{1}{2}(w/g)\,k^2\,[a_1^2\{\tfrac{1}{2}-(\sin 2\,ml/4\,ml)\}\,l - (a_1a_2/m)(\cosh ml\sin ml-\sinh ml\cos ml) + a_2^2\{(\sinh 2\,ml/4\,ml)-\tfrac{1}{2}\}\,l].$$

The work done by the centrifugal forces is found to be

$$-\tfrac{1}{2}(w/g)\,\Omega^2\,(1/m)\{(a_1^2/4)[\{(\sin 2\,ml-2\,ml\cos 2\,ml)/4\}+(2\,m^3l^3/3)] + (a_1a_2/2)\{\cosh ml\sin ml-\sinh ml\cos ml-2\,ml\sinh ml\sin ml\} + (a_2^2/4)[\{(2\,ml\cosh 2\,ml-\sinh 2\,ml)/4\}+(2\,m^3l^3/3)]\}.$$

With the value $ml = 5\pi/4$ we obtain the energy equation

$$\tfrac{1}{2}EIm^4l\,(0.436\,a_1^2+81.96\,a_2^2) = \tfrac{1}{2}(w/g)\,k^2l\,(0.436\,a_1^2+81.96\,a_2^2) - \tfrac{1}{2}(w/g)\,\Omega^2\,(1/m)\,(10.16\,a_1^2+70.62\,a_1a_2+565.1\,a_2^2).$$

Thus

$$k^2 = (EIm^4g/w)+(\Omega^2/ml)\,[(10.16\,a_1^2+70.62\,a_1a_2+565.1\,a_2^2)/(0.436\,a_1^2+81.96\,a_2^2)] = k_0^2+(4/5\pi)\,\Omega^2\,[(10.16\,a_1^2+70.62\,a_1a_2+565.1\,a_2^2)/(0.436\,a_1^2+81.96\,a_2^2)].$$

Consider the expression

$$u=(10.16\ a_1^2+70.62\ a_1a_2+565.1\ a_2^2)/(0.436\ a_1^2+81.96\ a_2^2).$$

The minimum value when a_1, a_2 are regarded as variables is found to be

$$u=4.96 \text{ approx.}$$

and the maximum value

$$u=25.38 \text{ approx.}$$

The corresponding coefficients of Ω^2 are 1.27 and 6.46.

The appropriate value is apparently 6.46 as this value is the only one approximately consistent with the condition

$$\Sigma mxY=0$$

where m is here the element of mass at the point x, Y.

Hence in this case the maximum value is the appropriate one and not the minimum one as in the encastré case.

Applying the Rayleigh Principle in the ordinary way we have at the outset $a_1=36\ a_2$ and we thus obtain 6.4 for the corresponding factor of Ω^2.

It appears that in the " free-free " case a simple expression for the elastic curve does not give a very close approximation for the fundamental unless the boundary conditions are satisfied at both ends.

Take for example the case of a tapered rod of unit length and whose area and flexural moment of inertia at a point distant x from the hinged end is given by

$$A_x=A_0\ (1-x)$$
$$I_x=I_0\ (1-x)^2.$$

In this case we assume the simple elastic curve

$$Y=a_1x+a_3x^3.$$

We then have the following boundary conditions satisfied

$$x=0,\ Y=0,\ d^2Y/dx^2=0.$$
$$x=1,\ EI_xd^2Y/dx^2=0,\ (d/dx)\ (EI_xd^2Y/dx^2)=0.$$

With the assumed curve we find

$$\int_0^1 EI_x\ (d^2Y/dx^2)^2\ dx=(6/5)\ EI_0a_3^2$$

$$\int_0^1 (\rho/g)\ A_xk^2Y^2dx=(\rho/g)\ A_0k^2\ [(a_1^2/12)+(a_1a_3/15)+(a_3^2/56)].$$

So that

$$k^2=56\times(6/5)\ (EI_0g/A_0\rho)\ [a_3^2/\ \{\ a_3^2+(56/15\ a_1a_3)+(14/3\ a_1^2)\ \}\ ]$$
$$=(336/5)\ (EI_0g/A_0\rho)\ \{\ 1/[(14/3)\ \{\ (a_1/a_3)+(2/5)\ \}^2+(19/75)]\ \}\ .$$

Thus the maximum value of k^2 occurs when $a_1/a_3=-2/5$ and will be given by

$$k^2=265.3\ (EI_0g/A_0\rho).$$

The approximate value for the fundamental derived from a series solution of the appropriate differential equation is

$$k^2=262.5\ (EI_0g/A_0\rho).$$

There is thus fairly close agreement.

It is to be noticed in this case that the value obtained for the fundamental k^2 is a maximum regarded as the appropriate energy function of the amplitudes and that such maximum value is in excess of the true value.

For the uniform case we may obtain a reasonable approximation to the fundamental by assuming the elastic curve

$$Y=a\ (x/l)+a_2\sin(\pi x/l).$$

This will satisfy the boundary conditions

$$x=0,\ Y=0,\ d^2Y/dx^2=0;\ x=l,\ d^2Y/dx^2=0.$$

We obtain in the usual manner

$$\int_0^l EI\,(d^2Y/dx^2)^2\,dx = EI\,(\pi^4/l^4)\,(a_2{}^2l/2)$$

$$\int_0^l (w/g)\,k^2Y^2dx = (w/g)\,k^2\,[(a_1{}^2l/3)+(2\,a_1a_2l/\pi)+(a_2{}^2l/2)]$$

$$-\int_0^l (w/g)\,x\Omega^2\,\{\int_0^x (dY/dx)^2\,dx\}\,dx = -(w/g)\,\Omega^2\,[(a_1{}^2l/3)+(2\,a_1a_2l/\pi)+1.52\,a_2{}^2l].$$

Hence

$$k^2=[\Omega^2\,\{(a_1{}^2/3)+(2\,a_1a_2/\pi)\}+\{1.52\,\Omega^2+(\lambda/2)\,a_2{}^2\}]/[(a_1{}^2/3)+(2\,a_1a_2/\pi)+(a_2{}^2/2)]$$

$$=\Omega^2+[\{1.02\,\Omega^2+(\lambda/2)\,a_2{}^2\}/\{(a_1{}^2/3)+(2\,a_1a_2/\pi)+(a_2{}^2/2)\}]$$

$$=\Omega^2+[\{1.02\,\Omega^2+(\lambda/2)\}/\{(\tfrac{1}{3})\{(a_1/a_2)+(3/\pi)\}^2+\tfrac{1}{2}-(3/\pi^2)\}]$$

where $\lambda=\pi^4EIg/wl^4$.

k^2 will evidently be a maximum when

$$a_1=-3\,a_2/\pi$$

and the maximum value will be found to be

$$k^2=2.55\,\lambda+6.20\,\Omega^2.$$

The more accurate value for k^2 when $\Omega^2=0$ is given by

$$k^2=2.44\,\lambda.$$

It is interesting to note that the relation between a_2 and a_1 for which the maximum occurs, viz., $a_1=-3\,a_2/\pi$ is exactly the one for which $\Sigma mxY=0$ for the assumed elastic curve.

§ 2. The Dunkerley "Empirical" Formula.

Reverting to the case of the light elastic rod carrying two concentrated loads dealt with in § 1.1, let

y_{11} = deflection at point 1 due to unit load applied at that point.
y_{12} = deflection at the point 2 due at unit load applied at point 1.
y_{21} = deflection at the point 1 due to unit load applied at point 2.
y_{22} = deflection at point 2 due to unit load applied at that point.

Then by one of Rayleigh's reciprocal theorems,

$$y_{21}=y_{12}.$$

In vibration we have

$$Y_1=m_1k^2Y_1y_{11}+m_2k^2Y_2y_{12}$$
$$Y_2=m_1k^2Y_1y_{12}+m_2k^2Y_2y_{22}.$$

Eliminating Y_1 and Y_2 from these equations, we obtain the frequency equation

$$m_1m_2\,(y_{11}y_{22}-y_{12}{}^2)\,k^4-(m_1y_{11}+m_2y_{22})\,k^2+1=0.$$

Hence

$$(1/k_1{}^2)+(1/k_2{}^2)=m_1y_{11}+m_2y_{22}$$
$$1/k_1{}^2k_2{}^2=m_1m_2\,(y_{11}y_{22}-y_{12}{}^2).$$

Now if m_2 were absent we should have

$$1/K_1{}^2=m_1y_{11}$$

and similarly if m_1 were absent we should have

$$1/K_2{}^2=m_2y_{22}.$$

Hence

$$(1/k_1^2)+(1/k_2^2)=(1/K_1^2)+(1/K_2^2).$$

Dunkerley* suggested the empirical formula

$$1/K^2=(1/K_1^2)+(1/K_2^2)$$

where $K/2\pi$ is the fundamental frequency for the pair of loads. Similarly for any number of loads.

Clearly the closeness of the approximation derived from the Dunkerley formula will be governed by the relative values of the overtones in terms of the fundamental.

Generally if we have n loads

$$\Sigma(1/k_1^2)=\Sigma(1/K_1^2)$$
$$\Sigma(1/k_1^2k_2^2)=\Sigma(1/K_1^2K_2^2)$$

where $K_1K_2/4\pi^2$ is the product of the two frequencies arising from W_1, W_2, together the remaining loads being zero; and so on.

Thus

$$\Sigma(1/k_1^2)=\Sigma m_1y_{11}$$
$$\Sigma(1/k_1^2k_2^2)=\Sigma m_1m_2(y_{11}y_{22}-y_{12}^2).\dagger$$

Also

$$\Sigma(1/k_1^2k_2^2k_3^2)=\Sigma m_1m_2m_3\begin{vmatrix} y_{11}y_{12}y_{13} \\ y_{12}y_{22}y_{23} \\ y_{13}y_{23}y_{33}\end{vmatrix}$$

and so on.

Closer approximations to the fundamental may be obtained by making use of the following identities:—

$$\Sigma(1/k_1^4)=\{\Sigma(1/k_1^2)\}^2-2\Sigma(1/k_1^2k_2^2)$$
$$\Sigma(1/k_1^6)=\Sigma(1/k_1^2)[\{\Sigma(1/k_1^2)\}^2-3\Sigma(1/k_1^2k_2^2)]+3\Sigma(1/k_1^2k_2^2\ k_3^2)$$
$$\Sigma(1/k_1^8)=\{\Sigma(1/k_1^4)\}^2-2[\{\Sigma(1/k_1^2k_2^2)\}^2-2\Sigma(1/k_1^2)\Sigma(1/k_1^2k_2^2k_3^2)$$
$$+2\Sigma(1/k_1^2k_2^2k_3^2k_4^2)].$$

The foregoing scheme of approximation apparently does not apply to the case of free-free vibrations.

It should be noticed that the Dunkerley formula gives an approximation which is below the true value and not above as is the case with the Rayleigh principle.

As an example of the application of the Dunkerley method consider the case of the tapered rod encastré at the root and whose area and flexural moment of inertia at a point distant x from the encastré end is given by

$$A_x=A_0\{1-(x/l)\}$$
$$I_x=I_0\{1-(x/l)\}^2$$

where l is the length of the rod.

Assume that unit load is attached at the point δ then we have at the point x ($<\delta$),

$$EI_xd^2Y/dx^2=\delta-x$$

or

$$EI_0\{1-(x/l)\}^2(d^2Y/dx^2)=\delta-x$$

which may be written

$$EI_0(X^2/l^2)\,d^2Y/dX^2=\delta-l+X$$

where

$$X=l-x.$$

On integration and having regard to the end conditions, we obtain

$$Y=(l^2/EI_0)[(l-\delta)\{\log X-(X/l)-\log l+1\}$$
$$+X\log X-X-X\log l+l].$$

---

* Phil. Trans. A. p. 279 (1894).

† See "Strength of Shafts in Vibration." Chap. III. J. Morris. (Crosly Lockwood.)

If the unit load is at the point x we find that

$$Y_{xx} = (l^2/EI_0)\,[2X(\log X - \log l) - (X^2/l) + l]$$

where as before $X = l - x$.

The weight of the element thickness dx at the point x is

$$w_x = \rho A_0 \{ 1 - (x/l) \}\, dx.$$

Hence

$$\Sigma m_1 y_{11} = \int_0^l (\rho A_0/EI_0 g)\, Xl\,[2X(\log X - \log l) - (X^2/l) + l]\, dX$$

which on evaluation is found to be

$$\rho A_0 l^4/36\, EI_0 g.$$

Thus

$$k^2 = 36\, EI_0 g/\rho A_0 l^4.$$

A more accurate value is

$$k^2 = 40\, EI_0 g/\rho A_0 l^4$$

so that the approximation for k will be of the order of 5 per cent. on the low side.

§3. Approximation by Series Solution.

If we take the case of the encastré tapered body considered in §1.3, with the following properties:—

$$A_x = 0.69\, ct_m \{ 1 - (x/l) \}^{3/2}$$
$$I_x = 0.05\, ct_m^3 \{ 1 - (x/l) \}^{7/2}$$

then the appropriate equation of motion is

$$(\partial^2/\partial x^2)\,[E \times 0.05\, ct_m^3 \{ 1 - (x/l) \}^{7/2} (\partial^2 y/\partial x^2)]$$
$$= -(\rho/g) \times 0.69\, ct_m \{ 1 - (x/l) \}^{3/2} (\partial^2 y/\partial t^2)$$

which may be written

$$(d^2/dX^2)\,(X^{7/2} d^2Y/dX^2) = \mu^2 X^{3/2} Y$$

where

$$X = l - x$$
$$y = Y \cos(kt + \varepsilon)$$

and

$$\mu^2 = 13.8\, \rho l^2 k^2/Et_m^2 g.$$

Assuming a series solution of the form

$$Y = X^\lambda (a_0 + a_1 X + a_2 X^2 + a_3 X^3 + \ldots)$$

we obtain the indical equation

$$\lambda(\lambda - 1)(\lambda + \tfrac{1}{2})\{\lambda + (3/2)\} = 0$$

and since Y must be finite when $X = 0$, the constants of integration multiplying the series corresponding to

$\lambda = -\frac{1}{2}$ and $\lambda = -3/2$ must be zero.

Hence we may assume that

$$Y = a_0 + a_1 X + a_2 X^2 + a_3 X^3 + \ldots$$

Applying this series to satisfy the original equation and equating coefficients we find that the appropriate solution is

$$Y = a_0 \left[1 + \{2^2\mu^2 X^2/(1 \cdot 2 \cdot 5 \cdot 7)\} + \{2^4\mu^4 X^4/(1 \cdot 2 \cdot 3 \cdot 4 \cdot 5 \cdot 7 \cdot 9 \cdot 11)\} + \{2^6\mu^6 X^6/(1 \cdot 2 \cdot 3 \cdot 4 \cdot 5 \cdot 6 \cdot 5 \cdot 7 \cdot 9 \cdot 11 \cdot 13 \cdot 15)\} \ldots\right]$$
$$+ a_1 \left[X + \{2^2\mu^2 X^3/(2 \cdot 3 \cdot 7 \cdot 9)\} + \{2^4\mu^4 X^5/(2 \cdot 3 \cdot 4 \cdot 5 \cdot 7 \cdot 9 \cdot 11 \cdot 13)\} + \{2^6\mu^6 X^7/(2 \cdot 3 \cdot 4 \cdot 5 \cdot 6 \cdot 7 \cdot 7 \cdot 9 \cdot 11 \cdot 13 \cdot 15 \cdot 17)\} \ldots\right].*$$

The end conditions are

$$X = l,\ Y = 0 \text{ and } dY/dX = 0.$$

* This series solution may be readily expressed in terms of Bessel functions, but for the purpose in hand the series form is retained.

Making use of these and after the elimination of a_0, a_1, we obtain the following equation in K^2:—

$$1-6.349\times10^{-3}K^2+6.343\times10^{-6}K^4-1.8425\times10^{-9}K^6+0.1953\times10^{-12}K^8=0$$

where

$$K^2=2^2\mu^2l^2.$$

Hence

$$\Sigma\,(1/K_1^2)=6.349\times10^{-3}$$
$$\Sigma\,(1/K_1^2K_2^2)=6.343\times10^{-6}$$
$$\Sigma\,(1/K_1^2K_2^2K_3^2)=1.8425\times10^{-9}$$
$$\Sigma\,(1/K_1^2K_2^2K_3^2K_4^2)=0.1953\times10^{-12}.$$

Thus

$$\Sigma\,(1/K_1^4)=\{\Sigma\,(1/K_1^2)\}^2-2\,\Sigma\,(1/K_1^2K_2^2)$$
$$=(6.349^2-2\times6.343)\,10^{-6}$$
$$=27.624\times10^{-6}.$$

From which we obtain the approximation

$$1/K_1^2=5.256\times10^{-3}$$
$$\Sigma\,(1/K_1^6)=\Sigma\,(1/K_1^2)\,[\,\{\Sigma\,(1/K_1^2)\}^2-3\,\Sigma\,(1/K_1^2K_2^2)]+3\,\Sigma\,(1/K_1^2K_2^2K_3^2)$$
$$=140.6406\times10^{-9}.$$

From which we obtain the closer approximation

$$1/K_1^2=5.200\times10^{-3}$$
$$\Sigma\,(1/K_1^8)=\{\Sigma\,(1/K_1^4)\}^2-2\,[\,\{\Sigma\,(1/K_1^2K_2^2)\}^2-2\,\Sigma\,(1/K_1^2)\,\Sigma\,(1/K_1^2K_2^2K_3^2)$$
$$+2\,\Sigma\,(1/K_1^2K_2^2K_3^2K_4^2)]$$
$$=728.628\times10^{-12}.$$

From which we find the still closer approximation

$$1/K_1^2=5.195\times10^{-3}.$$

Making use of this value in $\Sigma\,(1/K_1^6)$ we find

$$1/K_2^2=0.759\times10^{-3}\text{ app.}$$

and using the values of $1/K_1^2$, $1/K_2^2$ thus found we may obtain the value

$$1/K_3^2=0.243\times10^{-3}.$$

Thus

$$k_1:k_2:k_3=1:2.62:4.62.$$

To find the fundamental frequency

$$1/2^2\mu^2l^2=Et_m^2g/55.2\,\rho l^4k^2=5.195\times10^{-3}$$
$$\text{or } k/2\pi=0.298\,(t_m/l^2)\sqrt{(Eg/\rho)}$$

which agrees exactly with the value found earlier by the Rayleigh Principle (see § 1.3).

To gain some idea of the accuracy achieved by this method consider the solution of the equation

$$(d/dX)\,(X^{7/2}d\Phi/dX)+n^2k^2X^{5/2}\Phi=0$$

the conditions being

Φ finite for all values of X

$\Phi=0$ when $X=l$.

The appropriate series solution will be found to be

$$\Phi=a_0\,[1-(2\,n^2k^2/1\cdot7)\,X+(2^2n^4k^4/1\cdot2\cdot7\cdot9)\,X^2$$
$$-(2^3n^6k^6/1\cdot2\cdot3\cdot7\cdot9\cdot11)\,X^3+\ldots]$$

and the corresponding equation in $K^2\,(=2\,n^2k^2l)$ is

$$1-(K^2/1\cdot7)+(K^4/1\cdot2\cdot7\cdot9)-(K^6/1\cdot2\cdot3\cdot7\cdot9\cdot11)$$
$$+(K^8/1\cdot2\cdot3\cdot4\cdot7\cdot9\cdot11\cdot13)-\ldots=0.$$

Hence

$$\Sigma\,(1/K_1^2) = 1/7 = 0.142857$$
$$\Sigma\,(1/K_1^2K_2^2) = 1/126 = 0.0079365$$
$$\Sigma\,(1/K_1^2K_2^2K_3^2) = 1/4{,}158 = 0.000248$$
$$\Sigma\,(1/K_1^2K_2^2K_3^2K_4^2) = 1/216{,}216 = 0.00000093.$$

So that

$$\Sigma\,(1/K_1^4) = \{\Sigma(1/K_1^2)\}^2 - 2\,\Sigma(1/K_1^2K_2^2) = 0.004535$$
$$\Sigma\,(1/K_1^8) = \{\Sigma\,(1/K_1^4)\}^2 - 2\,[\{\Sigma\,(1/K_1^2K_2^2)\}^2 - 2\,\Sigma\,(1/K_1^2)\,\Sigma\,(1/K_1^2K_2^2K_3^2) + 2\Sigma\,(1/K_1^2K_2^2K_3^2K_4^2)]$$
$$= 0.00001\,38019.$$

From which we obtain the approximation

$$1/K_1^2 = \sqrt[4]{(0.00001\,38019)}$$

or

$$1/K_1^2 = 0.06096.$$

Using this value in

$$\Sigma\,(1/K_1^6) = \Sigma\,(1/K_1^2)\,[\{\Sigma\,(1/K_1^2)\}^2 - 3\,\Sigma\,(1/K_1^2K_2^2)] + 3\,\Sigma\,(1/K_1^2K_2^2K_3^2)$$

we obtain the approximation

$$1/K_2^2 = \sqrt[3]{\{\Sigma\,(1/K_1^6) - (1/K_1^6)\}}$$

or

$$1/K_2^2 = 0.0215.$$

Hence

$$k_2/k_1 = K_2/K_1 = \sqrt{(6{,}096/2{,}150)} = 1.7 \text{ app.}$$

Now the series solution obtained can be expressed by the Bessel function $J_x(x) = \{x^n/2^n\Pi(x)\}\,[1 - \{x^2/2(2n+2)\} + \{x^4/2.4(2n+2)(2n+4)\} - \ldots]$. where $n = 5/2$.

Thus

$$J_{5/2}(x) = [\{(x^{5/2})/(2^{5/2})\,\Pi\,(5/2)\}]\,[1 - \{(x^2/2)/1.7\} + \{(x^4/4)/(1.2.7.9)\} - \{(x^6/8)/(1.2.3.7.9.11)\} + \ldots].$$

The appropriate equation in K^2 may therefore be expressed as the series part of

$$J_{5/2}(\sqrt{2}\,K) = 0.$$

Now

$$J_{5/2}(x) \times \sqrt{(\tfrac{1}{2}\pi x)} = \{(3/x^2) - 1\}\sin x - (3/x)\cos x.$$

The first four roots of the equation in $\sqrt{2}\,K$ are found to be

$$\sqrt{2}\,K_1 = 5.764$$
$$\sqrt{2}\,K_2 = 9.096$$
$$\sqrt{2}\,K_3 = 12.323$$
$$\sqrt{2}\,K_4 = 15.515.$$

We have therefore

$$1/K_1^2 = 2/5.764^2 = 0.06019$$
$$k_2/k_1 = (\sqrt{2}\,K_2)/(\sqrt{2}\,K_1) = 9.096/5.764 = 1.56.$$

This case is a fairly severe test for the series approximation method as the frequencies are rather close to one another, being in the proportions.

$$1 : 1.56 : 2.14 : 2.65 \ldots$$

Appendix.

Note on Forced Vibration Experiments.

It is frequently desirable, when failures from forced vibration are suspected, to reproduce in tests the conditions as closely as may be in order to study the behaviour of the body or system affected and from the results observed to devise means for preventing the failure in question. The results of many such experiments are, however, often misleading and useless owing to misunderstanding as to what constitutes a forced vibration and its reproduction on test. As an example we will examine the case of a series of experiments carried out with the object of ascertaining the natural frequencies of the blades of an airscrew of which there had been many failures when used with a certain type of engine.

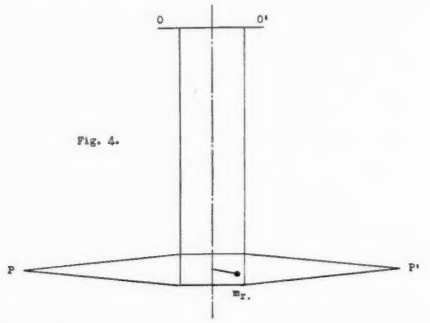

Fig. 4.

Referring to Fig. 4, PP' is an airscrew suspended by two lengths of shock absorber cord. Forced vibrations are set up by the rotation of an out of balance mass m_r by means of a pneumatic drive. The rotation is carried out at varying speeds and those noted for which violent agitation of the blades occurs. It may be considered that these speeds give the natural frequencies of the blades of the airscrew, but as will be shown this is not the case at all under the conditions of the test.

To simplify matters let the airscrew blades be regarded as two equal light flexible arms carrying equal tip masses m_1 at the ends.

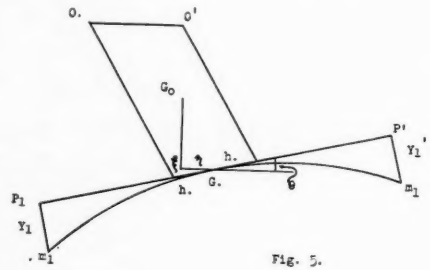

Fig. 5.

Referring to Fig. 5, at time t, let

ξ = vertical displacement of point G from position of rest G_o.
η = horizontal displacement of same point.
θ = angular displacement of mean line PP' of the arms.
Y_1, Y_1' = displacements of the tip masses m_1 from PP'.

All these displacements are in the first instance regarded as small.

Acting at G there will be a forcing vibration

$$m_r r\Omega^2 \cos \Omega t \text{ upwards}$$
$$\text{and } m_r r\Omega^2 \sin \Omega t \text{ horizontally,}$$

where m_r is the mass of the rotating load, and its radius and Ω its angular velocity.

The units chosen are engineer's units. Thus if r is in inches, Ω in radians/second, then m_r is in lb./g where g is in ins./sec.^{2} in which circumstances forces will be in lb. wt.

Regarding the flexible arms as cantilevers we obtain the following two equations of motion :—

$$Y_1 = -m_1 D^2 (\xi + L_1\theta + Y_1) y_{11}$$
$$Y_1' = -m_1 D^2 (\xi - L_1\theta + Y_1') y_{11}$$

where y_{11} = deflection in inches due to unit load at point of application of m_1.

L_1 = length of one of the arms,

and D is the operator d/dt.

Thus we find

$$Z_1 = -m_1 D^2 (\xi + Z_1) y_{11} \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$Z_1' = -m_1 D^2 (L_1\theta + Z_1') y_{11} \quad . \quad . \quad . \quad . \quad (2)$$

where

$$Z_1 = \tfrac{1}{2} (Y_1 + Y_1')$$
$$Z_1' = \tfrac{1}{2} (Y_1 - Y_1').$$

For the system in the vertical direction

$$(1/y_{11}) Z_1 = \lambda\xi + \tfrac{1}{2} m_r r\Omega^2 \cos \Omega t \quad . \quad . \quad . \quad . \quad (3)$$

where λ is such that for each length of shock absorber

$$T = \lambda\xi$$

where T is the additional tension due to the additional extension ξ.

Again by moments

$$(L_1/y_{11}) Z_1' = \lambda h^2\theta \quad . \quad . \quad . \quad . \quad . \quad (4)$$

It is obvious that the vibrations which may become resonant in this case are those for the co-ordinates Z_1 and ξ. Thus from equations (1) and (3) we derive respectively

$$[D^2 + (1/m_1 y_{11})] Z_1 = -D^2\xi$$

and

$$(1/y_{11}) D^2 Z_1 = \lambda D^2\xi - \tfrac{1}{2} m_r r\Omega^2 \cos \Omega t$$

so that by eliminating $D^2\xi$ we obtain

$$[\{(1 + 1/\lambda y_{11})\} D^2 + (1/m_1 y_{11})] Z_1 = (1/2\lambda) m_r r\Omega^2 \cos \Omega t \quad . \quad . \quad (5)$$

From this we deduce that there may be resonance with the vibration of frequency $k/2\pi$ where

$$1/k^2 = m_1 [y_{11} + (1/\lambda)]$$
$$= m_1 (y_{11} + \xi_{11})$$

where

$$\xi_{11} = 1/\lambda.$$

In general ξ_{11}, *i.e.*, the deflection of each shock absorber due to unit load will be greater than y_{11}.

Resonance will thus only occur with a free vibration of the system and not with that of a single arm about its root.

From (2) and (4) we obtain the equation

$$[\{1 + (L_1^2/h^2) (\xi_{11}/y_{11})\} D^2 + (1/m_1 y_{11})] Z_1' = 0$$

from which we derive the frequency $k/2\pi$ where

$$1/k^2 = m_1 \{y_{11} + (L_1^2/h^2) \xi_{11}\} \quad . \quad . \quad . \quad . \quad (6)$$

This vibration will be entirely free and in practice will be rapidly damped out.

If the forcing vibration consisted of a torque about G then the resonant vibration would be that given by (6), the previous vibration becoming entirely free.

We notice that the two frequencies of the system are both different from the frequency of a single arm about its root which frequency is $k/2\pi$ where

$$1/k^2 = m_1 y_{11} \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The vibration in the horizontal direction will be a forced one of frequency $\Omega/2\pi$ and may be avoided by arranging for two masses m_1 to rotate equally in opposite directions.

We observe, therefore, that the foregoing scheme does not reproduce the required conditions.

If instead of the rotating loads, a mechanism is arranged so as to constrain ξ such that

$$\xi = \xi_0 \cos \Omega t$$

where $\xi_0 =$ constant

then equation (1), para. 3, will become

$$(m_1 y_{11} D^2 + 1) Z_1 = m_1 y_{11} \xi_0 \Omega^2 \cos \Omega t.$$

In this case the free frequency will be

$$(1/2\pi) \sqrt{(1/m_1 y_{11})}$$

i.e., the frequency of one arm about its root and furthermore there may be resonance between this frequency and that of the forcing vibration.

Similarly if the forcing vibration is a constrained torque such that

$$\theta = \theta_0 \cos \Omega t$$

for in these circumstances we have by equation (2), para. 3,

$$(m_1 y_{11} D^2 + 1) Z_1' = m_1 L_1 \theta_0 \Omega^2 \cos \Omega t.$$

THE BUCKLING OF AN ELASTICALLY ENCASTRED STRUT.

By W. Prager, Istanbul University.

In a previous issue of this Journal (Vol. 40, pp.663-680, 1936) Mr. N. J. Hoff has investigated the buckling of an elastically encastred strut. The ingenious method used by Mr. Hoff consists in considering portions of various lengths of a *rigidly* encastred strut which is in a state of neutral equilibrium under the action of its critical compressive load. This load is also the critical load of an *elastically* encastred strut whose length is equal to the length of the considered portion, if only the rigidities of encastrement are chosen in accordance with the ratios of the slopes of the neutral axis at the ends of this portion to the bending moments there. The total length of the elastically encastred strut does not enter immediately into the formulæ derived by this method, there enter only two lengths x_1 and x_r whose sum is equal to the total length. These quantities are the distances between the ends of the considered portion of the *rigidly* encastred strut and the middle of its span. It seems, however, preferable to give the buckling condition of the elastically encastred strut in a form which contains immediately the total length of the strut. This condition can be easily obtained by specialisation of the buckling condition of an elastically supported and elastically encastred strut given in a previous paper of the present author ("Elastic Stability of Plane Frameworks," to appear in the *Journal of the Aeronautical Sciences*).

Using the following notations:—

l = length of the strut.
EI = flexural rigidity of the strut.
P = critical compressive load.
$\lambda = l\sqrt{(P/EI)}$.
y', y'' = deflections at the ends of the strut (Fig. 1).
R', R'' = reactions of the supports (Fig. 1).
θ', θ'' = angles of twist at the ends of the strut (Fig. 1).
M', M'' = encastrement moments (Fig. 1).
Ψ', Ψ'' = rigidity coefficients of the supports ($\Psi' = EIy'/l^3R'$, $\Psi'' = EIy''/l^3R''$).
Ω', Ω'' = rigidity coefficients of the encastrements ($\Omega' = EI\theta'/lM'$, $\Omega'' = EI\theta''/lM''$).

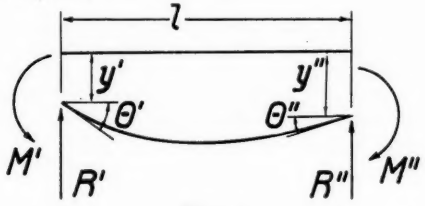

Fig. 1.

The buckling condition of the elastically supported and elastically encastred strut takes the following form:—

$$\Psi'\Omega'\{\Omega''E(\lambda) - D(\lambda)\} - \Psi'\{\Omega''D(\lambda) + B(\lambda)\} + \Omega'\{\Psi''\Omega''E(\lambda) - \Psi''D(\lambda) - \Omega''B(\lambda) + C(\lambda)\} - \Psi''\Omega''D(\lambda) - \Psi''B(\lambda) + \Omega''C(\lambda) + A(\lambda) = 0, \quad . \quad . \quad . \quad (1)$$

where $A(\lambda)=(1/\lambda^4)(2\cos\lambda+\lambda\sin\lambda-2)$.
$B(\lambda)=(1/\lambda)\sin\lambda$,
$C(\lambda)=(1/\lambda^3)(\lambda\cos\lambda-\sin\lambda)$.
$D(\lambda)=\cos\lambda$.
$E(\lambda)=\lambda\sin\lambda$.

A table of numerical values of the functions A, B, C, D, E, has been given in the paper mentioned above.

Equation (1) contains as border cases the buckling conditions of the well known four elementary cases of the hinged-hinged, the hinged-clamped, the clamped-free and the clamped-clamped strut. For the clamped-free strut, for instance, we have at the clamped end $y'=0$, $\theta'=0$ and at the free end $R''=0$, $M''=0$. The coefficients representing the end conditions take therefore the values $\Psi'=0$, $\Omega'=0$, $\Psi''=\infty$, $\Omega''=\infty$. Consequently only the term $-\Psi''\Omega''D(\lambda)$ of the left side of equation (1) has to be retained, as all other terms vanish beside it. The buckling condition thus obtained is $D(\lambda)=0$, it admits as the smallest positive root $\lambda=\pi/2$. By the definition of λ (see notations) this gives the well-known value $P=(\pi^2/4)(EI/l^2)$ for the critical compressive load of the clamped-free strut.

To obtain from equation (1) the buckling condition of the rigidly supported and elastically encastred strut ($\Psi'=\Psi''=0$), we have only to suppress those terms on the left side of equation (1) which contain the factors Ψ' or Ψ''. The buckling condition thus obtained is:—

$$\Omega'\Omega''B(\lambda)-(\Omega'+\Omega'')C(\lambda)-A(\lambda)=0 \quad . \quad . \quad . \quad (2)$$

The smallest positive root of this equation corresponding to any given values of the encastrement coefficients Ω' and Ω'' can be easily found from the nomogram

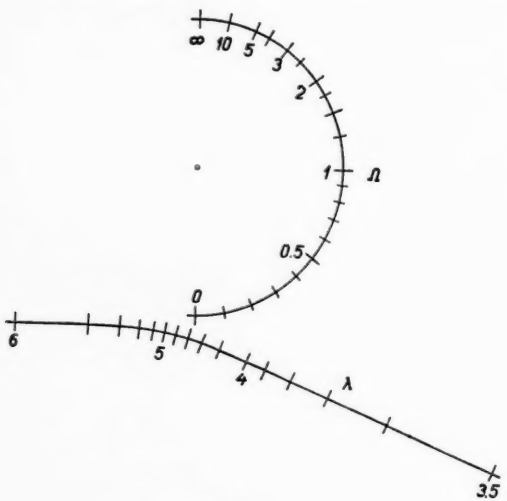

FIG. 2.

given in Fig. 2. The line joining the points of the semi-circle whose graduations are the given values of Ω' and Ω'' meets the other graduation in the point corresponding to the required root λ. This root being known, the critical compressive load of the elastically encastred strut can be easily calculated as $P=\lambda^2(EI/l^2)$.

REVIEWS.

THE ANALYSIS OF ENGINEERING STRUCTURES.

A. J. S. Pippard, M.B.E., D.Sc., M.Inst.C.E., F.R.Ae.S., and J. F. Baker, M.A., D.Sc., Assoc.M.Inst.C.E. Edward Arnold and Co., Ltd. 1936. 30/- net.

There is an increasing tendency in all branches of education to specialise. There is no doubt that too early specialisation of training fails to give that broad outlook and above all that sound understanding of fundamental bases of knowledge which are essential for constructive progress and clear judgment.

This tendency for specialisation has become very evident in aircraft engineering. There are specialists in aerodynamics, in structures, in engines, in aerodrome construction, and so on, each of whom have only an elementary and often hazy knowledge of the other's problems. Worse still, books are appearing which deliberately foster the idea that there is no need to learn mathematical principles or the basic principles of engineering. They foster it in two ways, *e.g.*, by elaborating methods which avoid, say, the calculus, or by setting out formulas to be used for the solutions of particular problems, with very little warning of the dangers of using such formulas without a thorough understanding of the way they have been derived.

No aircraft engineer can consider himself fully qualified to solve the problems of design and construction, which are his everyday problems, unless he has had a proper general engineering training before any question of specialisation arises. The reviewer welcomes, therefore, any book which can serve to provide that training. Without any equivocation "The Analysis of Engineering Structures" is such a book. It is, unquestionably, the most ably written and most authoritative book on engineering structures published during the past fifteen years, years which have seen, in some respects, a most fruitful advance in engineering methods generally.

The reviewer's bible was "Theory of Structures," by A. Morley, which deservedly became an engineering classic, but has not kept pace with the newer methods of structural analysis. Pippard and Baker have written a book which, the reviewer predicts, will become the classic textbook of the present generation and one which will prove of immense value also to the older, practising engineer, whether aeronautical or civil.

Chapter 1 deals with definitions and general principles and Chapter 2 with primary stress analysis of statically determinate frames. Here we are introduced to the elegant method of tension coefficients put forward by Professor R. V. Southwell, together with a completely worked out example. The method is also applied in Chapter 4 to stress energy equations. It is one which has the merits of simplicity and accuracy.

Chapter 3 on stress in straight and curved beams contains certain important sections, particularly section 3.17 on bending stresses in curved beams.

Strain energy methods, used extensively in the first instance in aeronautical engineering, are considered at length in Chapter 4. The exposition is clear and simple. Chapter 5, on elastic displacements, follows logically, with further use of strain energy methods, and the Williot-Mohr graphical method of obtaining displacements of a braced frame is given with a worked out example.

In Chapter 6 the authors consider the stress analysis of redundant frames. In section 6.6 the important, and comparatively recent method (1930) of succes-

sive approximation, due to Professor Hardy Cross, for determining stresses in highly redundant rigidly jointed frames, is discussed. This is one of the really important developments of structure analysis of recent years and the authors are to be congratulated for including it. It is discussed at greater length in Chapter 9 on stiff-jointed frames, to which the method is peculiarly applicable. The labour involved in the solution of many simultaneous equations by older methods has compelled the engineer to find other methods and that introduced by Professor Cross is one which must come into general use. In section 6.7 the authors set out Southwell's relaxion method which has the advantage of avoiding all simultaneous equations and is chiefly concerned with the determination of the deformations of the structure. Here again a worked out example makes the method refreshingly clear. Section 6.9 on the design of redundant frames and the effect of curved bars in a framework are both of real value to the aircraft engineer.

Much of the treatment of Chapter 7 on struts and laterally loaded columns and ties follows that of other workers in the same field. Attention may be drawn, however, to section 7.20 on initially curved struts with end couples and to the exposition of Howard's neat polar diagram method which has taken its place as a standard method during the past few years.

Chapter 8 is concerned with continuous beams and columns. In section 8.4 the Cross method is further developed with examples. Chapter 9 on frames with stiff joints is one which will repay the study of every aircraft designer. In Chapter 10 the important subject of secondary stresses is considered and follows naturally on the subject matter of the previous chapter, and here again the Cross method is applied. Chapter 11 deals with the behaviour of connections in steel frames and Professor Batho's construction.

Chapter 13 deals with the theory of composite structures and reinforced concrete. Reinforced concrete is unlikely to be used in aircraft, but the reinforced materials certainly will and the chapter will repay study.

In Chapter 14 the effect of rolling loads is dealt with and the important work of Professor Inglis on the treatment of vibrations in railway bridges. The chapter on the influence lines for statically determinate structures is followed by a similar one for indeterminate structures. The short following chapter on flat slabs and plates reveals the present difficulties of finding simple solutions to the problems that are present in modern building construction.

Chapter 19 on the design of steel framed buildings is one of general importance in view of the rapid increase in recent years of such type of building. The chapter consists largely of a description of the work carried out by the Steel Structures Research Committee and published in three reports in 1931, 1934 and 1936.

The book ends with a very useful account on mechanical methods of stress analysis on which the authors themselves have carried out important investigations. Much of the work and many of the methods described throughout the book, indeed, are in the first instance due to the authors themselves and is published for the first time.

The authors in their preface write: "The primary object of this book is to present to the student of engineering a general outline of the theories upon which the design of structures is based."

Professors Pippard and Baker have completely succeeded in their primary object. The book is an example of how it should be done, in matter, in style, and in production, for which the publishers are deservedly to be praised. The book is illustrated throughout with worked out examples and many exercises and contains, finally, that most useful of all things, a properly prepared index.

It is a book which can be whole-heartedly recommended to the aeronautical engineer, who must be up to date in modern engineering methods. Professor Southwell once said that aeronautical engineering is ordinary engineering made more difficult. Professors Pippard and Baker have succeeded in making more difficult engineering appear simple.

BIRD FLIGHT.

By Gordon C. Aymar. Published by John Lane. Price 12/6.

This book is largely a collection of bird photographs with a little letterpress, mainly descriptive, but it contains by far the best collection of these photographs ever published. Here we find many sorts of birds soaring, flying, landing on earth and water, and rising from both elements. Some of them are doing unusual things, flying through a three-inch gap in a wall, making a bad landing on a tree top, or carrying objects, such as rabbits, but in every case the photograph is excellent and the whole should add materially to our knowledge of bird flight.

There is still much to be learnt in this field and the lessons may be of great importance in the design of aeroplanes. Why, for instance, are the wing tip feathers of certain birds spread out like the fingers of a hand while others of approximately the same weight and habits cannot perform this manœuvre. The author's explanation that these feathers act as slots is not convincing, and the probability is that the action is connected with propulsion. But herein arises a difficulty; it might be an advantage to certain types of birds to adopt a wing modification which increased the efficiency of flapping at the expense of a loss in gliding angle, so that it is not necessarily advisable to adopt such modifications to our aeroplanes.

With regard to carrier pigeons, the author states that these birds lose their sense of direction if released near a large wireless aerial engaged in transmitting. Others have suggested that this happens, and it would seem to be advisable that an arrangement should be made between the Aeronautical Research Committee and some selected carrier pigeon club to test the truth of it directly. Rugby would seem to be an excellent site for such a test and it might be that we should obtain some light on that mysterious homing instinct, full knowledge of which might revolutionise navigation.

This book appears at an opportune moment for there is now an awakening interest on the subject of bird flight, and the complications of the problems involved are well shown in many of the photographs in this book. It is to be hoped that it will encourage others to photograph in this field as it is seldom a good bird photograph does not add to our knowledge.

CORRESPONDENCE.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

THE JOINTING OF MATERIALS BY WELDING.

Sir,—With regard to Mr. Myers' communication he states that "Welding is the one process that inspection cannot get inside to verify." I cannot accept that as a serious statement of fact, no inspector can get inside to verify riveting or to satisfy himself that the last turn of a nut before riveting over or pinning up did not strip a thread.

The whole process of the manufacture of metallic materials prohibits such inspection. All that can be accomplished is strict control of the various operations and conditions.

He also refers to the metallic material now embodied being extremely sensitive, but he must also be aware of the numerous B.E.S.A. and D.T.D. specifications covering metallic materials suitable for welding.

There is no great difficulty in this country in obtaining suitable operators. As proof of this Mr. Myers should very easily be able to find out from his own department how many welders have been approved by A.I.D. during the past twelve months or so and also how many of those were not welding aircraft components at the commencement of the expansion programme.

With regard to repairs, the maintenance of the true form and alignment of the various components is undoubtedly of great importance, but does Mr. Myers honestly consider that such alignment has not been maintained on the numerous repairs of welded aircraft and components which have been carried out and passed by A.I.D. during the last few years?

It is quite evident that Mr. Myers is not thoroughly conversant with modern welded construction and workshop practice, otherwise he would know that it was possible to carry out satisfactory repairs without the use of special appliances as he terms them. These I presume to be jigs, but it is nowadays an unwritten law that all welding shall be carried out with the structure free to expand and contract and this, of course, prohibits the use of special appliances during manufacture.

In conclusion, if a welded framework be out of truth it is a simple matter to replace a strut, and this is surely a better method than risking the possibility of having bracing wires over-tightened by a careless mechanic.—Yours, etc.,

R. H. DOBSON.

A. V. ROE, LTD.

21st September, 1936.

The 609th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS.

A meeting of the Royal Aeronautical Society was held in the Lecture Hall of the Royal Society of Arts, at 18, John Street, Adelphi, London, W.C.2, on Thursday, October 22nd, 1936, when a paper on "The Economics of Air Line Operation," by Mr. L. T. H. Greig (Director of Jersey Airways, Ltd.), was presented and discussed.

The PRESIDENT of the Society (Mr. H. E. Wimperis) presided. Introducing Mr. Greig, he said that he, together with Mr. W. L. Thurgood, had founded Jersey Airways, Ltd., as recently as 1933—only three years ago—and in that short space of time he had made the Jersey Air Line the success that it had become.

THE ECONOMICS OF AIR LINE OPERATION.

By L. T. H. GREIG, Esq.

(*Director of Jersey Airways, Ltd.*).

In speaking to you to-night on the Economics of Air Line Operation, I propose to speak primarily from the viewpoint of the operator of an internal air line. I do not mean, by that, that I shall confine my remarks strictly to the various problems encountered by my own particular company, nor do I mean that any opinions which I may express will, of necessity, be of interest only to operators of internal services. On the other hand, I do not intend to venture into the realms of very long distance air routes, such as Empire routes, many of the problems connected with which have already been dealt with in considerable detail by Mr. Woods Humphrey in his interesting series of articles in *The Times* in May of this year. Such small experience as I have had so far with international flying has convinced me that the political difficulties, which are undoubtedly encountered by many of the national air transport companies, must force upon them policies other than those dictated by strictly economic requirements, and in consequence, must render a true comparison between their operation and purely European flying almost impossible. It is therefore, from the very special viewpoint of the operator of an internal air line and in the light of experience gained under very specialised conditions of operation that I shall speak to-night.

The very special conditions under which my company has operated up to the present, render the usual array of passenger ton mile figures comparatively valueless. Such matters as the use of a tidal beach as an aerodrome, necessitating continual change of schedules, and imposing a severe limitation upon the number of possible services per day, serve to distort any figures, which I could give you, beyond useful comparison with normal operating conditions.

I therefore propose to speak principally from the rather general standpoint of the problems which have to be faced and solved when organising a new air line. Many of the points to which I shall draw attention may be, and probably are, almost too obvious to warrant comment, but as in almost every other type of business, successful air line operation is really dependent upon the introduction in the economic system of the company of a multitude of just such apparently obvious factors.

Perhaps the most important factor of all, which governs the whole economic policy of an air line is the choice of route. Upon this one factor, for example, will depend the type of aircraft to be used, its size, speed, carrying capacity in relation to cabin accommodation, the type of passenger to be catered for, and hence, the form of ground transport, if any, to be provided. Even the office organisation will be largely affected, and, in short, upon this one factor, the whole complexion of the company's operating policy will depend.

Turning to more detailed considerations, there are, in general, four main types of internal air line in this country:—

1. The very short ferry service.
2. The air line serving substantial centres of population with stops at distances of not more than 200 miles apart.
3. The air line principally serving centres of population 300 to 400 miles apart, and
4. The air lines crossing substantial distances of sea.

In each case, the first question to be asked is whether the proposed air line will, in practice, give the travelling public a tangible advantage over their alternative means of transport. Considering this point, the transit time that matters is the total time which will elapse from the moment of the passenger's departure from a central point in the town of embarkation to the time of his arrival at a similar central point in the town of his destination. A certain percentage of passengers will, of course, make their own way to the aerodrome at the one end, and from the aerodrome at the other, but by far the majority of the passengers to be carried should, for successful operation, regard air transport merely as a means of getting from A to B a little more quickly, or a little more comfortably than they have been in the habit of doing.

Members of the public are largely creatures of habit in so far as transport is concerned, and it is very difficult to change these habits successfully. If the change is restricted to mode of transport between thoroughly familiar destinations, the problem of inducing large numbers of the public to take to the air becomes greatly simplified. The smaller the advantage that air transport has to offer on a particular route, the greater the need for studying the habits of the travelling public, and the greater the risk that will be entailed if those habits are seriously interfered with. Thus, the first type of air service referred to, the very short ferry service, is immediately faced with an extremely difficult problem. Not only is much time unavoidably wasted in ground transport to and from the aerodrome at each end, but the competitive means of transport takes such a relatively short time in the normal course of events that some very considerable inducement has to be offered before really heavy and continuous traffic can be expected. I do not mean that heavy traffic will not be carried in any circumstances, since there will, even for a year or two yet, still be numbers of people who will look upon such a service in the light of a cheap joy-ride. I think, however, that such a service cannot be expected to attract steady support all the year round from those who travel for business reasons. The effect of this upon the economics of such a project must be obvious.

All the many and varied overhead charges must be borne by the revenue obtained during relatively few months in the year, staff salaries to all but purely seasonal staff will have to be borne in the same way, while the percentage of flying time of the aircraft, compared with waiting time on the ground, will begin to rise in an alarming manner. The ultimate result, of course, is that any short ferry service of this nature becomes faced with almost insuperable difficulties, and if it succeeds in earning a profit over a period of years, its management can undoubtedly congratulate themselves upon having achieved a phenomenally high standard of efficiency.

The operator of the internal air line of about 200 miles in length is faced with a more interesting problem in many respects, but is, at the same time, deprived

of any prospects of being able to attract an appreciable amount of joy-riding traffic, which even though seasonal, may help to tide an otherwise useful air line over its initial difficult stages.

Consider for a moment the situation that would be faced by a company endeavouring to operate an air service between, say, Edinburgh and Newcastle. The distance is approximately 90 miles by air, a fast train completes the journey in 2½ hours, but before the air line operator can even commence to fly, he is faced with a road journey between the aerodromes at each end and the centres of the cities in question, which will involve a total of at least 45 minutes. In addition, there will be the inevitable time wasted in circuits and taxi-ing, embarkation and disembarkation, together with greater or lesser delays due to head winds and the like. The total liability in respect of ground operation will therefore be approximately 55 minutes. If it is borne in mind that a special train of the " Silver Jubilee " class has already reduced the time of this journey by 36 minutes, then the total time remaining for the air journey and for the saving in time, without which few passengers could be expected to travel, will only be one hour. Even with aircraft cruising at 200 miles per hour, the air journey would still take half an hour, a degree of saving which, by itself, is quite insufficient to attract substantial traffic.

Again, aircraft, particularly the relatively small class of fast aircraft, cannot as yet compare with the comfort of first class rail travel. Clearly, therefore, for the type of service referred to, some other inducement would have to be sought. The only other inducement which aircraft have to offer is flexibility and frequency of service, and the only hope that such a service could have for success would, in my opinion, lie in the provision of something analogous to the service provided by the London tube railway. It would, however, take an enormous amount of traffic to keep even one aircraft in almost continuous operation, and, economically speaking, such a project would be a tremendous risk.

Much the same problem would be encountered with almost any other route, which is to be operated between points served by a main line rail service. This point, of course, gives rise to the question of whether cross-country air routes would not pay, but here again, the natural inertia of the travelling public has to be borne in mind, and I think it is a fair comment that in the majority of cases, if there is no good rail service between two centres of population, then it is improbable that there is sufficient demand for such a service to be warranted.

It is always possible to institute an air service between two points in the hope that when the facility is provided, the public will make use of it, but unless the public is already in the habit of travelling between those two points by some means of conveyance, the process of creating new traffic will be a very slow and painful business, likely to be far too costly for the ordinary commercial undertaking.

The case of the third type of air line is considerably more hopeful, however. The time lost in ground transport, embarkation, etc., will still be very much of the order of that involved in the shorter journey, though it is probably true to say that the larger the centre of population to be served, the further the terminal aerodrome will be from the centre of the city, and the greater the time that will be lost in ground transport. Thus, in the case of an air line between London and Edinburgh, flying normally non-stop between these two points, the total time absorbed by ground operations will rise to about one and a half hours. The distance by air between the two points is some 340 miles, and an average cruising speed of 170 miles per hour will see the total journey completed in 3½ hours from centre to centre.

This period compares with approximately seven hours by rail, and at first sight would appear to offer quite a tangible benefit to the passenger. It must be remembered, however, that in the present stage of aerial science, it is not possible to operate over such a route with train-like regularity. At the same time, in order to be on a profit-earning basis, the fares charged would, of

necessity, be in the region of first class rail fare or higher. Thus, the type of passenger to be catered for would be the substantial business man, who is in a hurry, and who simply cannot afford to put up with the very type of irregular operational schedules which such a service would be likely to encounter.

To some extent, this difficulty might be overcome by frequency of operation, but in practice, it is more than probable that the demand for transport would prove to take place only at certain very set times of day. A certain percentage of traffic might be expected to arise from persons preferring to remain overnight, either at home or in a hotel, and utilising air transport to enable them to keep an appointment during the following afternoon instead of, as at present, being compelled to travel all night in order to avoid wasting a whole day.

Similarly, certain traffic might be expected from persons desiring to proceed to their destination after completing the greater part of a day's work. There is little likelihood, however, that any material traffic, by comparison, would be encountered during the rest of the day, and any advantage to be gained by frequency on routes where the total journey time exceeds about two hours, would, in all probability, therefore, prove to be negligible. It is, however, very evident that without quite a high cruising speed, even an air route of 350 miles between stops, has small prospect of success if in competition with highly efficient rail services.

In all three of the types of air line operation discussed so far, the dominating factor has been the very competitive services offered by other means of transport, and in particular, by main line rail transport. The true economic needs of aircraft as a primary means of transport have, in consequence, been largely obscured by the conditions imposed by powerful competition.

The fourth type of air line operation, that in which the route lies over substantial distances of sea, leaves the air line operator in the fortunate position of being able to offer substantial inducements to the travelling public, both in the way of time saving and of comfort, and the problem of creating a demand for air transport, largely ceases to exist.

It is the remaining consideration, however, namely, the methods by which the demand for transport can best be met, that is perhaps the truest indication of the economics of air line operation as we know it to-day. Since we may take it, therefore, that in so far as this particular type of operation is concerned, the problem of securing initial traffic has been largely solved, the next important point to consider, in view of the fact that water is to be crossed, is whether land aircraft, flying boats, or some hybrid type of aircraft shall be used.

The case for the sea-going craft has been put forward very frequently and by very able men. Imperial Airways, after prolonged and successful operation with land aircraft, have placed orders for not less than 29 very large flying boats, and a well-known American designer has even worked out tentative plans for a flying boat of no less than a thousand tons gross weight.

As I have already pointed out, however, the problems which beset Imperial Airways are considerably greater than the relatively simple problems of straightforward operation, and the present instability of the international situation, coupled with the tremendous importance of being able to maintain our Empire communications intact under any circumstances, may, in itself, be more than sufficient to warrant the change, irrespective of economic considerations. There are also such trials and tribulations as monsoons which flood aerodromes, and generally the problems with which that company is faced are plainly so vastly different to anything which is likely to be encountered in the vicinity of the British Isles, that no useful purpose will be served in attempting to draw comparisons.

There is, however, one characteristic of seagoing aircraft, which is beyond dispute, and which, in my view, precludes their use for serious air transport around the shores of these islands. I refer, of course, to the necessity for

carrying out both take-off and landings in relatively sheltered water. I am, of course, open to correction, but I do not believe that even Canopus could be operated successfully under open sea conditions, especially as encountered in the Channel, and the provision of artificial areas of sheltered water of sufficient size would, in most cases, prove a hopelessly extravagant undertaking.

I am not going to enter into a discussion on the technical possibilities of flying boats versus land planes, though, personally, I am unable to see how a hull can be at one and the same time both aerodynamically and hydrodynamically correct, but since the operation of flying boats around these shores would manifestly involve either heavy expenditure in providing suitable stretches of sheltered water, or difficulty in maintaining reliable schedules, both of which are economically unsound, the only remaining excuse, in my view, for operating seagoing aircraft would be if it were found impossible to achieve reasonably safe operation without them.

It seems to me that in these days of high-speed aircraft having four engines and being capable of maintaining reasonable height with any two engines out of action, the risk of a forced landing in the sea through aircraft or engine trouble has been reduced to such a low level that it can reasonably be disregarded. If it is felt, however, that the risks of a particular crossing are too great to permit even this degree of uncertainty to be countenanced, then it seems to me that the correct procedure should be to use a land aircraft so designed as to be capable of remaining afloat for an extended period when forced down on water. Such an aircraft would provide most of the efficiency of a normal land plane, while at the same time providing protection in the event of a forced landing in the sea in any reasonable sort of weather. In really rough weather its chances of survival would be little, if any, worse than those of a flying boat, particularly if the latter were of the type employing wing tip floats.

It is, therefore, fairly evident that from an economic standpoint, flying boats must be ruled out in so far as air services in the vicinity of the British Isles are concerned.

The problem, consequently, is resolved into the simple one of deciding what type of land plane to use. The first problem is perhaps speed versus carrying capacity. In this connection, as Mr. Woods Humphrey very clearly pointed out in the series of articles to which I referred at the commencement of this talk, speed can be a very expensive luxury indeed.

For example, take the case of our own company's operation between Heston and the Channel Islands. The distance by air is approximately 185 miles, and with aircraft having a normal cruising speed of the order of 130 m.p.h., this journey takes, including taxi-ing and circuits, approximately 1½ hours. An increase in cruising speed to 200 m.p.h. would reduce the journey time to approximately one hour. The time taken to unload and re-load the aircraft would, however, remain the same, and, in practice, only one extra return journey a day would be possible with the faster aircraft.

On the face of it, this should be an advantage, but in practice it means that the extra service would have to be operated at a time of day when the general public are not anxious to travel, and in consequence, unless the demand for accommodation greatly exceeds the available supply, the only effect of an increase in speed would be to perform the same number of journeys as the slower aircraft, but to do so in rather less flying time. The effect of this, of course, would be to spread overhead costs over a smaller number of flying hours, thus increasing the cost per flying hour, and, in this case, per mile as well.

Let us for a moment examine the question of speed on a *reductio ad absurdum* basis. Let us suppose that two aircraft cost exactly the same sum of money per mile to fly, provided that they are both flying exactly the same number of flying hours per year, as is approximately true in the case of the two types D.H. 84 and D.H. 89. Let us, however, further suppose that the one aircraft performs a certain journey in one hour's flying time, but that the other aircraft

is so fast that it performs the same journey almost instantaneously. It is, of course, perfectly evident that the fast aeroplane would spend such a large percentage of its time being unloaded and re-loaded, that it would be almost impossible for it to put in the same number of flying hours as the slower machine. It is further obvious that a great deal of the flying would take place at times of the day when nobody wished to travel, and the net result would be that the fast aeroplane would be so fabulously expensive to operate under practical conditions that it could not be used. The same state of affairs, on a smaller scale, of course, is true of every air line once a certain speed is exceeded. What that speed will be, will depend entirely upon local conditions, but, in every case, a very definite figure will be found above which any further increase in speed will serve merely to reduce the total number of flying hours performed, and to increase the cost per hour, and hence per mile.

On the other hand, it is unwise to sacrifice too much speed for the sake of carrying capacity. An extra ten or fifteen minutes' flying will not be greatly resented by the travelling public, even in the case of quite a short air journey, if the reduced speed enables really competitive fares to be offered, but at the same time, it must be borne in mind that aircraft cruising at much less than 130 m.p.h. become very subject to delay through adverse winds, and such irregularities necessitate increased time allowances for unloading and re-loading, necessitate the carrying of a greater reserve of fuel, with a consequent loss of payload, and tend to spoil punctuality of operation, which, in turn, tends to drive away traffic.

There is, therefore, an optimum speed for each particular service, and any departure from this optimum speed will give rise to inefficiency.

The next problem to be faced is that of frequency of operation versus large carrying capacity, flying infrequently. Here again, an accurate decision can only be taken with regard to a particular service, but, in general, it should be borne in mind that if a service is scheduled it must be flown, whether the aircraft is empty or not. The practice of cancelling services because no passenger happens to have booked to travel, very rapidly discourages chance passengers, and simply leads to chaos. It must be obvious, therefore, that, other things being equal, a small number of services with a large capacity per service can be more efficiently operated than a large number of services with a small capacity per service. This brings me to my final point with regard to types of aircraft, that of size versus plurality of units.

The question here is whether to adopt the policy of using small numbers of very large aircraft, or that of using larger numbers of somewhat smaller aircraft. In this connection, Imperial Airways, who operate representative aircraft of both types, have expressed the opinion that the larger aircraft are cheaper to operate, in proportion, than the smaller aircraft. They are, however, not faced with by any means the same problem as the small operating companies, in that, since large aircraft became available, the minimum average demand for accommodation on their services has been sufficient to warrant the use of such large aircraft. Moreover, their traffic, though undoubtedly subject to " peaks " as is every other form of transport, does not, I feel sure, suffer from the same acute fluctuations as those which beset the average internal operator.

In the case of my own company, the " peak " loads encountered are as much as fifteen times the minimum load offering. Surely, therefore, the governing factors must be:—

(1) The minimum average load offering.
(2) The minimum size of aircraft capable of giving the requisite standard of comfort and efficiency.

For example, if the traffic on a given route rarely drops below 25 in each direction per service, and if the low average figure is of the order of 30, then it is plainly more economical to use a number of aircraft seating, say, 35, than to use a substantially larger number of aircraft seating, say, 15.

If, on the other hand, the minimum average demand is of the order of 12, with a " peak " demand of 100 or so, then quite clearly the most economic method of handling the situation will be to use a number of aircraft seating about 15 people, provided that such aircraft fulfil the minimum requirements of comfort and safety. In short, the wider the fluctuation of the traffic, the more desirable does it become to have a fleet of aircraft all of about the same type, size and speed, and to treat them all for traffic purposes as carriages in a train, which can be uncoupled if they are not required.

Thus, in effect, the capacity available on any given service may be adjusted within quite wide limits to suit the particular demand, while the consequences of some minor mechanical trouble, such as a punctured tyre, become reduced to a minimum.

There remains little more to say on this subject, for if an air line is founded upon a basis of sound policy with regard to its equipment, if its personnel are competent and conscientious in their individual jobs, the remainder of the problems to be faced are only those which are faced and solved in every well-run business. It is axiomatic that the technical services of pilotage and maintenance must be beyond reproach and that the company's seat reservation machinery must work smoothly and infallibly. There is no publicity quite as bad as that given by a disgruntled passenger whose seat reservation has gone astray, and the whole undertaking must operate at a high standard of efficiency if a profit-earning basis of operation is to be achieved.

On the purely commercial side of the undertaking there are two possible policies, the one being that of catering deliberately for luxury traffic only, or, on the other hand, of operating at the lowest possible fares consistent with safe operation and reasonable comfort. In the former case, high fares, luxuriously-appointed aircraft and ground transport, imposing offices and a surplus of smartly-uniformed assistants will be the outward and visible signs of a high cost per passenger mile. The number of passengers carried will be relatively low, but the revenue per head will be relatively high. In the other case, every aspect of the undertaking will be quite plainly meant for hard work. Many of the refinements associated with luxury air travel will be conspicuous by their absence, but the fares charged will, in all probability, bear comparison very favourably with other forms of transport, and the number of passengers likely to avail themselves of the facilities offered will be far higher. The profit per passenger will be considerably less, the margin of error permissible without causing loss will be substantially smaller, but the total turnover will be substantially greater. There will be less temptation for competitive air services to develop, and the air line will, in short, tend to become more of a utility and less of a luxury type, and as such will be less liable to suffer during times of financial depression.

The decision as to which general policy a particular air line's operation shall be based upon will depend, very greatly, upon purely local considerations. For example, if the main movement of traffic is caused by the activities of the substantial business man, then it is probable that the best results will be obtained by catering for luxury traffic. On the other hand, if all classes of traffic are represented in the general movement, then a utility basis is almost certain to yield the best results in the long run and, moreover, the substantially lower fares charged will serve to carry a new company through its initial development period of light traffic comparatively quickly.

Interest in air travel is as a practical means of transport. The problem, after all, is not one of persuading members of the public who have already experienced air travel to use a new service which is offered to them. In my experience, the first problem to be overcome is that of persuading hard-headed business men, who for the most part have never flown before and who, largely thanks to adverse press propaganda, are firmly convinced that flying is a most hazardous occupation engaged in largely by the very foolish or the mentally defective, that it is to their advantage to pay a rather higher fare than they are accustomed to doing

in order to get to their destination rather more rapidly, provided that nothing unforeseen occurs.

A wealthy man is, if anything, even more averse than the majority of us to spending more money upon transport than he is absolutely compelled to do, and one of the consequences of the high fares associated with luxury air transport is that the process of persuading members of the public into the air for the first time becomes much more difficult, and takes much longer.

I have purposely omitted all reference to either freight traffic or mail traffic, since I have, as yet, no practical experience of either form of traffic, but at the same time from such information as I have, up to the present, been able to obtain, it seems fairly certain that, in so far as the relatively short internal air lines of this country are concerned, both freight and mail should be carried well outside the hours during which passenger traffic can normally be expected to take place. In some respects this is unfortunate, in that night flying would be involved, and I am afraid that at present the air line operators of this country, for the most part, lack the necessary experience to operate a regular night service with the requisite degree of regularity and safety. In addition, few, if any, of the aerodromes that would be required to be used have the necessary ground equipment to make a regular night service really safe. I have, in discussing night flying, quite frequently heard the remark passed that under given conditions it is quite all right with freight, because you can't frighten freight. At the same time, I feel that any operator who adopted this policy of sending a freight aeroplane where he would not be prepared to send a load of passengers, would hardly be likely to endear himself to my good friend Captain Lamplugh, though it is of course quite possible that he would become very popular with the aircraft manufacturing fraternity.

I am sure Captain Lamplugh finds great pleasure in buying us all new aeroplanes every now and then, but I don't think he likes to do so too frequently. If an operator allows his pilots to take risks when flying freight that he would not allow them to take when flying passengers, sooner or later Captain Lamplugh will be looking for another nice new aeroplane and, having a rather strange sense of humour, will probably do distressing things to the rates of premium when renewing insurance policies. On the other hand, of course, provided that an operator does not try to run before he has learned to crawl properly, there seems no reason why a reasonably safe night service should not be operated.

Provided that the technical considerations involved can be satisfactorily dealt with, a night service for freight and mail offers very great advantages from an economic standpoint. One of the chief difficulties which appears to be associated with most of these types of businesses, but more especially with mail, is the impossibility of forecasting with real certainty how the demand for payload will fluctuate. In the case of mail, it must be remembered, His Majesty's Post Office, in addition to being a Government department, is, strangely enough, a highly efficient business organisation, and, as such, it not unnaturally buys its transport from the cheapest supplier consistent with satisfactory service. It would, therefore, be a rather dangerous gamble for an internal air line operator to purchase special equipment for the sole purpose of flying mails and freight. If, however, an operator is able to utilise, during part of the night, aircraft which are of utility for carrying passenger traffic during the day, the situation becomes considerably simpler and the risk entailed by the loss of a mail contract to a competitor becomes far less serious

A freight service does not carry the same risk of loss of a substantial portion of this particular class of business at one time, but it does, in many cases, suffer from extreme fluctuation in demand for accommodation.

There are, in conclusion, only two other points to which I think I can usefully refer to-night. One is the problem of co-ordinating the activities of the various sections of the staff of an air line, and the other is the problem of training the staff. I think perhaps the first problem is one of the most frequent sources of

inefficiency in a new organisation and, in the case of air line work, seems almost as insoluble as the classical conundrum relating to the immovable object and the irresistible force, only in this case there are three parties to the argument. It seems that pilotage, engineering and traffic staffs of any air line are forever carrying on some form of private warfare, even though, as I am thankful to say is true of my own company, it is all carried on in the friendliest possible spirit.

Pilots it seems do not really like encumbering an otherwise perfectly good aeroplane with a group of quite unintelligent passengers. Both pilots and traffic staff invariably want to use a particular aeroplane just at the very moment that the engineering staff have decided to take it completely to pieces to find out whether anything has gone wrong with it. The engineers, of course, view pilots rather in the light of barbarians who persistently undo all their good work on the aircraft, while in an engineer's eyes the traffic staff seem to take an altogether unholy delight in saying first that an aeroplane shall not be required and then, immediately it has been nicely opened up for inspection, finding an extra two or three passengers that they have not thought of before and demanding that the aeroplane be made ready for service in ten minutes. The traffic staff, for their part, are convinced that the engineers would take every aeroplane to pieces and stow it away in the hangars neatly, to prevent the pilots or anyone else playing with it, if they could only think of an excuse for doing so, while the ways of the pilotage staff are regarded as being beyond the understanding of the ordinary mortal.

Consider, for example, the feelings of the unfortunate traffic officer who, at the remote terminus, has to face a crowd of irritable passengers with a tale of fog and bad visibility, while overhead there is, in all probability, a blue sky and bright sunshine. Misunderstandings and friction are almost inevitable, perhaps more especially so if the individual members of staff are really keen and conscientious. The most that can be hoped for, therefore, is to keep such misunderstandings upon a friendly basis, and by careful selection of the types of individuals to be employed, to prevent anything worse than friendly rivalry developing.

Careful and detailed organisation of the duties of each department will go a very long way towards eliminating these difficulties, but in the ultimate the characters of the individual members of staff employed will be the deciding factor as to whether a company works happily, smoothly and efficiently, or whether its activities will be hampered and rendered inefficient by petty jealousy and internal intrigues.

Not unnaturally the training of individual members of the staff will have a very great bearing upon their relationship with their fellows. From my own experience, for what it is worth, the appointment of staff on the basis of their paper qualifications, instead of purely upon the basis of their work, almost invariably leads to injustices of one sort or another. These in turn lead to ill feeling, and so the whole vicious circle of internal intrigue is started. Any sort of favouritism or appointment of individuals because they are friends or relatives of some influential person has even more devastating effects upon the morale of the company.

My personal preference is entirely for appointing non-technical staff at all events purely upon the basis of their personalities and general common sense. Again, the degree of responsibility, which I allow an individual member of staff to assume, is almost entirely governed by his capacity to take over progressively more responsible work. Age or previous experience have little bearing upon the question, and indeed, in so far as traffic is concerned, I have found that the more experience an applicant, for the most part, has had of passenger traffic generally, the less likely he is to reach the quite high standard of efficiency that I require. With technical staff matters are, of course, somewhat different, but again the policy of promotion solely upon the basis of results achieved appears to produce the best results, both as regards work and as regards general morale.

Finally, may I say that as an air line operator I can appreciate the magnitude of the task which must face the management of Imperial Airways, not only from the standpoint of technical considerations, but also from the far more troublesome standpoint of staff organisation. It is not an easy matter to keep the peace even in a small organisation where, in case of need, any member of the staff can be spoken to by telephone, and in which the senior members of staff, at all events, are in comparatively frequent contact with the management.

In the case of Imperial Airways, however, the management is faced with a huge staff whose very names, with rare exceptions, are almost unknown to them, and who are scattered in remote corners of the earth, living under innumerable variations of local conditions.

The wide recognition which the present high standard of quiet efficiency achieved by Imperial Airways has earned, is, in my opinion, the highest tribute which it is possible to pay to the management of that great company.

Discussion.

Major R. H. S. Mealing (Chief Technical Assistant on the staff of the Director-General of Civil Aviation) ; He expressed gratitude to Mr. Greig for an extremely interesting paper, and added that inasmuch as it was entitled " The Economics of Air Line Operation," he had hoped to learn more from it concerning the economic side of it. Not much had been stated in the paper with regard to the costs of running an air line—but perhaps one could not blame Mr. Greig, for some of his competitors were present at the meeting!

Major Mealing emphasised, however, the remarks made in the paper concerning the time that could be saved by using aeroplanes in preference to other means of transport ; for example, the author had pointed out that certain traffic might be expected from persons desiring to proceed to their destination after completing the greater part of a day's work. During the last few months, he said, one had heard references to certain air lines which were only just carrying on, and it was necessary to consider carefully the reasons why they were only just carrying on. Was there not something in the argument that perhaps they were not providing what was wanted. In air transport they wanted something that could be used by business men, who could not afford to spend a whole day travelling ; they had to work during the day and could travel only in the mornings and evenings. But they had not yet provided the services they required. It was of no use squealing and saying that internal air routes were no good ; those who had faith in internal air transport knew very well that it was of great use and would be of greater use in the future if the machines were operated at the time they were required. He saw no reason why evening and early morning air services should not compete seriously with railway sleeping cars.

It was true, as the author had said, that the ground facilities available in this country were not adequate for the operation of a night mail and freight service. At the same time, he was not able to say whether anybody would put up a proposition for the carrying of mails and freight by air at night if the necessary facilities were provided. It was a matter of economics and a matter for the Treasury.

As to the types of machines to be used, the author had favoured the land plane for services in the British Isles, even where the routes involved sea crossings. For obvious reasons, the land plane would do more than any other type of machine at an economic rate. But—although he did not wish to be dismal—Major Mealing said it was just possible that some day a land plane might descend on the water, and he suggested, therefore, that the machines might be designed so that they would be able to remain afloat on the water if they were forced down, even though they were not able to take off again from the water. He was not advocating the old type of amphibian, the shortcomings of which were well known, but he suggested that a machine might be designed which was approxi-

mately 75 per cent. land plane and 25 per cent. sea plane. Such a machine would be able to remain afloat on the water and yet would retain all the qualities of the fast land plane as they knew it to-day.

Mr. HOLLIS WILLIAMS (*Associate Fellow*): Nothing more than Mr. Greig's paper was required to demonstrate the lamentable state of civil aviation internally in this country to-day. It was quite true that England possessed some very serious disadvantages from the point of view of the internal air line operator ; flying distances were short, and ground distances from airports to municipal centres were relatively long, and ground organisations poor, so that at first sight there would appear to be ample reasons for discouragement. But he did not think the problem was quite so bad as it appeared to be, for there were several factors in favour of air travel which must not be discounted. In the first place, it was very easy for an operator of an air line to provide services and individual attention of a character which the passengers would appreciate, even assuming that they saved neither time nor money by air travel. A railway undertaking, for instance, did not pick up its passengers at their homes and convey them to the rail terminus, or convey them from the arrival terminus to their ultimate destinations. But a well organised air line could quite easily make such provision, collecting from a ring of hotels in large centres and actual homes in small centres. This service is offered by the air lines of America and directly one makes a reservation, the question is asked " Where can we pick you up, and do you require a car at the other end?" The organisation of transport facilities in this way is very much appreciated, and there is no reason why the same service should not be offered by the air lines of this country as the passenger pays extra for these transport facilities, although at a slightly lower rate than the equivalent taxi fare. In consequence everyone is satisfied, and one continually hears the remark in America that the air lines are the best public carriers in the world.

Again, when considering point to point times, there is one important feature which must not be overlooked, and that is, that when going to a railway station one is travelling inwards to a point of traffic congestion, whereas to an airport one is travelling outwards. In consequence, although distances are greater, road traffic in many cases is faster—the difference in time may easily be saved by greater parking facilities at an airport compared with the railway termini. This applies to the average traveller who travels from his home to the airport by car. Thus at one end of the journey the chances are that the traveller experiences no more difficulty in getting to the airport than the railway station, and in consequence the impression made upon his mind is the shortness of the flying time from his home airport to the centre to be visited. These are small points, but none the less very important points, as the speaker realised on a recent extended tour of the network of American air lines.

The speaker also stressed the point that where a journey involved a sea crossing, air travel had a great advantage, for the air traveller saved the enormous amount of time that was involved in the change from train to boat, and vice-versa, and avoided the dislocation which resulted therefrom. There were many routes within the British Isles to which that argument applied and some operators had had the wisdom to take advantage of it.

The lecturer had considered the economics of air line operation from the point of view of one air route only with specialised features. When considering the problem in a general way, however, it is necessary to find a more definite revenue basis in order to work out the £ s. d. of air line operation. The only sound basis seems to be to work out carefully how many hours per day a certain type of aircraft can be kept in the air, and then by wise selection of route to make sure of a reasonable supply of passengers. It is probable in order to attain this end that a network of routes will be required to avoid over-working any one route. On this basis one could then consider factors such as speed, capital cost, depreciation and consumption and maintenance, and it could be demonstrated

that speed was definitely an economical advantage, assuming that a 50 per cent. capacity load of passengers were available.

The criterion then being the number of passenger miles flown per period.

The benefit of a refined aircraft using all modern aerodynamic and engine improvements to cover as much ground as possible, with efficient expenditure of power, was obvious, which was contrary to the lecturer's conclusion that on his own route speed was not important.

Mr. S. A. Dismore (Imperial Airways, Ltd.): He thanked the author for the tribute he had paid to Imperial Airways, Ltd., complimented him on his record as a business man and welcomed his interesting paper on the business lines of air transport. Commenting upon the statement in the paper that Imperial Airways, Ltd., were not faced with the same problem as the small air operating companies, in that since large aircraft had become available the minimum demand for accommodation had been sufficient to warrant the use of large aircraft on Imperial Airways routes, he said that that was true to some extent; but they had had to build up the traffic to its present volume, for example in 1919, when he had first become connected with air transport, the aircraft passenger was a rarity. Of course, in those days, when considering the economics of air transport, he had been afraid to talk about a ton-mile, for it represented so large an amount of money; there was a temptation at that time to convert costs to terms of lb.-miles, in order to arrive at a manageable figure and one which was not too frightening!

The provision of smart uniforms for the staff and of apparently luxurious offices were not necessarily indications of high costs per passenger mile, because it might be due to the provision of such aids that an operating company was able to secure a good number of passengers.

Finally, Mr. Dismore said that when anyone talked to him about so-called scientific economics he always pointed out that there was one good thing to learn—the theory of inaccurate arithmetic, which was that 2 and 2 made 4 and left 1 over.

Mr. Farey Jones: The author had mentioned four different types of air line and had concentrated upon internal air lines, but had made no general recommendations as to what operators should do in order to develop internal air lines. The economics of the problem were contingent upon several factors. For instance, the manufacturers must produce at some time in the future—they had not produced it yet—for internal air line operation a machine which could be operated not only during eight or twelve hours of the day, but all round the clock, proper allowance being made in respect of the periods during which each machine would be withdrawn from service for purposes of overhaul, etc. If an air line were to be operated economically, the operators should engage in air line operation only. That statement might sound ridiculous, but it was not really so ridiculous. Reference had been made in the paper to the amount of time lost in travelling, on the ground, to and from air ports, and that indicated an attitude of mind on the part of British air line operators which was entirely wrong. The travelling public had not yet been taught to regard an aerodrome much as they regarded St. Pancras, Euston, or any other large railway terminus. If they wished to travel from London to Edinburgh by train they did not expect the railway companies to provide a coach and horses for the purpose of conveying them to the station; and if they travelled to Piccadilly Circus station by tube railway they did not expect the railway undertaking to provide them with special conveyances to their destinations. The economics of internal air line operation had become more and more dependent upon the co-relation of air lines and allied forms of transport; the trouble in this country was that they had regarded the railways and the motor coaches as competitive means of transport with aerial transport. Mr. Greig had admitted that the operator of an air route which involved a sea crossing could virtually put his fingers to his nose and point out that air travel was very much quicker than any other mode of travel. But one

wanted to see the allied forms of transport feeding the internal air lines, and one wanted to see facilities provided by the Air Ministry which would enable air lines to be operated all round the clock. The matter should be regarded from the point of view of providing air lines which people could use; should they consider the provision of air travel facilities which would take a business man to town in the morning, take him home to lunch and back again to town, and which would take his wife shopping in the afternoons? The problem had been considered in the past from the point of view of providing a service from, say, Bristol to Heston, or from Heston to the Channel Islands; nobody in this country had had sufficient money, or had had the correct aeroplanes, or had had the necessary facilities to run a service, say, all round the British Isles, six times a day, with perhaps as many as 16 stops. Had they considered the advantages which would be derived from the actual running of machines carrying ten passengers and with engines having a take-off value of perhaps 400 h.p., which machines could make a minimum of eight stops on a total route of 1,600 miles? He visualised a service from London via the eastern side of the country to Edinburgh, thence to Glasgow, down the western side of the country via Liverpool and Bristol, and then back to London, with intermediate stops at suitable places, and urged that they should consider the effect of providing such a service. With regard to the actual machines, he said the trouble so far had been that every aeroplane that was available at a reasonable price involved an expenditure of at least half its capital cost in respect of maintenance over a period of twelve months. They were looking for a machine which could be pegged out at night for a period of three months without suffering any serious harm; they needed engines that would run on reasonable octane fuels, which would give greater speeds and which at the same time would not involve maintenance costs such as those of an R.A.F. engine. The manufacturers must wake up, more and more assistance was required from the Air Ministry in providing night landing and fog landing facilities, and the operators must give the public what they wanted in the way of comfortable travel at a reasonable price. Without those three conditions, and also a desire on the part of the railways and other forms of transport to regard air line operators as their friends instead of as competitors, he was afraid that it was of no use discussing the economics of air line operation at all.

Miss KENNEDY (*Companion*): Would the general public of the future who wished to travel over long distance routes, two days or more, prefer greater speed or more comfort? Would they be prepared to pay a higher rate for more passenger space in larger aircraft?

Mr. S. J. NOEL-BROWN: Commenting on the remark made by Mr. Farey Jones, that the aircraft manufacturers had not provided the type of machines the operators wanted, he said that there was one good reason, namely, that the operators themselves did not know their requirements. He recalled that a month or so ago operators were asked, in the pages of a technical aviation journal, what they wanted; about seven or eight large operators had stated what they required, but no two of them had agreed. How can the manufacturers give the operators what they require as regards aircraft if the operators themselves do not know what they want?

Although Mr. Greig had given a clear outline of the subject of air line operation, he had not, in his opinion, defined sufficiently the different types of service. Special aeroplanes were required for special purposes; in order to illustrate his argument, Mr. Noel-Brown mentioned three different types of services: (1) Services operating over distances of from 200 to 700 miles and having reasonable passenger and freight traffic, which services would require special aeroplanes; (2) internal services operating over distances of from 100 to 200 miles; and (3) ferry services. The first type of service, he said, called for the use of medium size, speedy aircraft. Economics governed the decision as to the number or size of the engines, or the horse-power, and the horse-power

in turn controlled the size of the machine and thus the passenger capacity. The first essential of air line operation was reliability, and the second regularity; and, in order to ensure regularity, the schedules must take account of head winds. During 92 per cent. of the year 1935, winds averaged 12 miles per hour throughout the whole of the United Kingdom, 7.5 per cent. of the year between 12 and 25 miles per hour, and 0.5 per cent. more than 25 miles per hour. Therefore, if the manufacturers really wished to provide what the operators required they should surely be machines having sufficient power to enable them to maintain their scheduled speeds against winds up to 25 miles per hour. Thus, the light wind journeys could be made well throttled, and the degree of throttling is greater on the slow machines than on the higher speed types. On the longer routes, such as those in category (1), where the scheduled block-to-block speed approaches the cruising speed, it can be shown that it pays to expend up to 100 h.p. per passenger, provided the power is used efficiently. For ferry services, category (3), the position is exactly the opposite. On short ferry services the time occupied at each end in taking off and landing had a curiously levelling effect, so that the block-to-block speed was much the same as for high or low speed aircraft. Under those circumstances the lowest powered machines showed the greatest economy, and satisfactory operation could be maintained with operating horse-power as low as 20 or 25 per passenger, as against 100 h.p. per passenger on higher speed machines, which operate at 75 per cent. power at rated altitude.

With regard to the problem of attracting passengers to air lines, Mr. Noel-Brown asked whether aircraft operators in this country had not made the mistake of trying to operate services on much the same lines as the operators of railways, coaches, and other means of surface travel. Had they not forgotten, he asked, that when a man wanted to travel he wanted to be able to travel when he was ready to go; if he were ready to make a journey to the Channel Islands, for instance, he wanted to go at once and saw no reason why he should have to wait several hours. In America the theory of frequency had been proved. In order to operate a service every hour, on the hour, an operator should use small economic machines as a start, for in the initial stages, when passengers were perhaps few, he could not afford to use big machines. The small machines should be kept in service as much as possible, and the operator should keep a number of spare engines. He should have a spare machine for every two machines in operation, and would operate economically; for every three machines in service (including the spare machine) he could have two spare engines, and still operate economically. Mr. Noel-Brown had in mind a machine which would operate for two hours per day at an all-in cost of 105s. (£5 5s. 0d.) per flying hour. If that same machine was operated for six hours per day, the all-in cost per flying hour was reduced to 50s. (£2 10s. 0d.). That, he said, was an argument for frequency. Another argument was that the possibilities of dislocation due to bad weather were minimised by frequency. For example, if one were operating, say eight or ten services a day, and if there were fog during the morning so that the 8.0 o'clock, 9.0 o'clock and 10.0 o'clock services had to be cancelled, and from 11.0 o'clock onwards the ordinary services could be operated, it did not result in the dislocation of the entire system; also, there would be machines available to cope with such dislocation as had occurred, if any, as the result of one or two passengers being held over from other machines.

Having developed traffic by the " every hour on the hour " principle, or on general frequency principles, the size of the machines used could be increased as the traffic became greater; and with the size of machines increasing, likewise speed increased. Those larger and faster machines would reduce operating costs, provided the power plant was economical, commensurate with speed, and operating on the service only when ample passenger traffic was always available.

Group Captain W. H. PRIMROSE (*Associate*): The paper had aroused controversy. The operators were telling the manufacturers what they were not

supplying but should supply, whilst the manufacturers were telling the operators how to operate their lines and what machines they should use; but they seemed to get no further. Little reference was made in the paper to methods of attracting passengers, and probably the author was wise in having skirted that thorny subject. He might or might not have made arrangements whereby he secured the benefit of the services of the great booking agencies; but until means of booking and arranging passages were provided in respect of air transport in the same way as they were provided in respect of surface transport, the travelling public would not go out of their way to reserve accommodation in aeroplanes by telephone or by other means, and so the traffic would not be attracted to the air lines. He asked for Mr. Greig's opinion on that matter.

It seemed that Mr. Greig had poured cold water upon the subject of providing night air services. Until air line operators showed a little more enthusiasm for night services they should never have night services, for the Air Ministry would never be sure that the plant it provided for the purpose would be used, and until the Air Ministry did provide such plant the operators would continue to say that they would provide night flying services, of course, if they had the necessary ground equipment to enable them to do it! They in this country were inclined to say that they had not the necessary experience; but they would never gain the experience until they began. The problem of carrying mails was very much wrapped up with that of night flying. The cost of air line operation, and consequently the charges to the public as travellers, could be lowered by running machines day and night, thereby increasing frequency of use. Surely the development or otherwise of the carriage of freight and mails by night had not to depend upon the views of Captain Lamplugh or any other insurance people as to the risk. Let the operators prove that the risk was not so great as Captain Lamplugh and others might consider.

Mr. H. STUART-SHAW (Imperial Airways, Ltd.): Speaking as a traffic official of lengthy experience in this and other countries, he said he felt a little anxiety about the author's statement, with regard to the appointment of staff, that "in so far as traffic is concerned, I have found that the more experience an applicant, for the most part, has had of passenger traffic generally, the less likely he is to reach the quite high standard of efficiency that I require." Mr. Stuart-Shaw enquired whether that was really the author's point of view on that subject.

Mr. E. C. GORDON ENGLAND (*Fellow*): He always listened to papers, lectures or discussions concerning air transport and the economics of air transport with very mixed feelings; Mr. Greig's paper might be considered as a case in point, for he seemed to have put forward a very excellent statement as to why they should not proceed with air transport, if his basis of approach were correct! It seemed that those concerned with air transport were always trying to prove that the public owed them some debt of gratitude for having provided the services and that the public really ought to patronise those services, and he suggested that perhaps that was the fundamental mistake that was made in approaching the problem of air traffic generally. There could be only one reason, apart from matters of high politics (such as Imperial defence, and the like), for operating air services, and that was that those services should perform some useful function in the social life of the community. Surely, therefore, if they were to get anywhere, they must approach the problem from the point of view of providing something useful to the public. It was not so much a question of whether people wanted luxury, or speed, or novelty; they wanted something which could be useful, something which could become a habit. It seemed that the fundamental question to consider was whether they could make air transport a habit, for it appeared, in considering any economic problem of that nature, that a service became practical only when it became a social habit. He felt that a good deal of harm was being done to air transport by demanding support from the community rather than by earning it. They did not provide facilities which he considered were reasonable. Mr. Farey Jones had rendered great service by

putting his finger on the essential point that they were confusing the issue by trying to mix air transport problems with those of terminal losses. It seemed that air line operators were apologising to their customers for the fact that they had to lose some time at both ends of an air journey, but telling them that it would be awfully jolly when they got going. That was not the commercial way of approaching anybody; was it not essential to be able to say that the service was provided, knowing perfectly well that people would *need* to use it? So long as they knew of its existence, provided it was needed, they would patronise it more and more. If he were feeling vindictive against the railways and other forms of surface transport he could prove cases of terminal losses which would shake them. But why should he complicate matters? A fact which annoyed him intensely was that whereas, if he wished to travel by tube railway, he could slip a coin into a machine, take a ticket from the machine and travel at once; he had to go through a formula before he could travel by air; he had to book his ticket, which was supplied with much pomp and circumstance which savoured of condescension on the part of the air operators, particularly as they insisted on weighing him too. But they had no right to treat him like that; he was speaking now as an ignorant member of the public. The tube railway operators did not deal with him in that way; they liked to see him putting pennies into the slot, and endeavoured to dispose the slot machine more conveniently so that his expenditure of effort became less and less. When asked why air transport was rendered difficult for the passenger by surrounding it with an extraordinary formula, they should say, if they were honest with themselves, that they were merely trying to hide their own inefficiencies. They should try to remove the difficulties, and make the aerodromes recognised points of departure and arrival. The whole history of transportation showed that the greater the travel facilities that were provided, the more the public would travel. If they could get into the minds of the public the idea that they could go somewhere by air without being troubled by an extraordinary amount of cumbersome machinery, and if they would cease making apologies, they would really get to the heart of the problem.

As to technical efficiency, operators attacked the manufacturers for not providing the right goods. Mr. Gordon England did not think any manufacturers would say for a moment that they were providing the right goods, for they did not know what was needed, any more than did the operators; but the manufacturers were willing to try, and they were trying. Then there was the demand for the right support from the Air Ministry; that was an extremely important point, and one on which the future of air transport in this country would depend. The public would not be allowed to travel in railway trains or other public vehicles if the facilities and the safety devices were not of the highest order and of uniform quality. Any railway company which had a magnificent signalling system, the most modern switchgear for its points, and so on, on the first portion of its track, and a completely different and elementary system ten miles down the track, would be in trouble at once. Similarly, they could not regard aviation parochially; it must be regarded as a whole. They could not have one type of service on an aerodrome in the south of England and totally different systems in the midlands and in the north; there must be complete uniformity of ground organisation before they could even attempt a system of air transportation of real service to the public. That position definitely placed on the shoulders of the Air Ministry the necessity for a decision which called for a great deal of courage. It might mean a great deal of preparation, say politically, in order to secure that decision, but that decision would have to be that it was in the interests of the country to provide a perfectly uniform system of ground service over which air lines could operate. He believed that until that position was reached they would be beating the air to a large extent.

Major D. H. Kennedy (*Fellow*): As the result of the discussion he had been impressed by their failure to recognise what could be learned from their past experience. Imperial Airways, Ltd., were carrying on a splendid Empire air line.

With regard to internal air lines, the Jersey Company was working under special conditions, where the circumstances happened to be very favourable. He had the utmost sympathy with Mr. Greig when he pointed out that there was no encouragement for anyone to invest capital in internal air lines, under present conditions. Before Imperial Airways, Ltd., had been established a number of companies had been cutting each other's throats. As a result, Parliament had had to recognise its duty and take steps to provide the conditions which had made Imperial Airways possible, and it had since had to recognise its duty by giving to Imperial Airways that security of tenure which was enabling them to carry on for another series of years. But no encouragement whatever was given to ordinary internal airways, and Parliament had failed gravely to recognise its duty in the matter. The Air Ministry had announced, through its representative in Parliament, that, commencing in 1937, first-class letter traffic was to be carried by air. Since that announcement was made he had waited with the greatest interest to see what Parliament would do to provide the necessary facilities, because obviously one could not expect capital to be invested in aeroplanes for that purpose unless there were some security of mail contracts to enable a service to be commenced. He asked what was being done, by Parliament, the Air Ministry, or other authority, to provide the proper facilities for the mail service.

Group Captain W. H. PRIMROSE (*Associate*) (late of the General Post Office) interposed to say that the carriage of first-class mail on the Empire air routes was to be commenced in 1937. Some time ago (he believed it was at the end of 1934) the Postmaster-General had announced that he would send by air all first-class letter mail which could be carried by an air transport company at a reasonable rate, where useful acceleration of the mail could be achieved. Obviously, the acceleration of the mails during the night so that they would arrive at the destination towns in time to enable them to be delivered to offices or houses at 4 a.m. instead of at 8 a.m. would not be a useful acceleration. But where the mail could, by the use of air services, be made to arrive in time for delivery by the first post in the morning instead of by the second or later post (as might be the case, for instance, in respect of the mail from London to Aberdeen), that would be regarded as useful acceleration. The Postmaster-General had promised that any operating companies which could give such a service at a reasonable cost would be given a chance of contracts for the carriage of mail provided they could undertake to carry it regularly. That promise would be fulfilled as and when facilities were provided.

Mr. W. V. WHEATLEY (Imperial Airways, Ltd.): Commenting upon the view that air transport would become popular only when it was as easy to travel by air as by rail, he suggested that one of the main attractions of air transport was that the passengers were looked after individually. In his experience he had not found that passengers complained of difficulty in booking seats, provided the accommodation was available; indeed, numerous letters had been received, stating that the passengers had appreciated the attention paid them. He referred to a recent journey he had made to Brighton by the Southern Railway, when it was extremely difficult to find a seat. He had had to wait for about half an hour at the booking office because there was a long line of people in front of him, and the crowd on the platform was so great that he could hardly get into a carriage. As a contrast, each passenger travelling by air had a seat ready for him and did not have to fight for it.

Flight Lieutenant J. C. BELFORD: Since the cost of travelling by air between two given points is greater than the cost of travelling by train, is not this the basic factor in economics of air line operation?

The PRESIDENT (Mr. H. E. Wimperis): It seemed to him that internal air transport systems should work amicably with the existing railway systems and endeavour to provide for the public facilities which they did not yet enjoy. Commenting on the author's reference to the railway journey from London to

Edinburgh, which occupied about seven hours in daytime, the President said that if one travelled by night the journey occupied eight or nine hours, and one could occupy a sleeper; the train arrived in Edinburgh at a convenient hour in the morning. If, however, one travelled to Edinburgh at night by air at the speed mentioned by the author, the journey would be completed in about $3\frac{1}{2}$ hours and one would be turned out of bed at about three o'clock in the morning, which would be very unattractive. He would not regard that as an additional facility, but rather as a disadvantage. The distance between London and Inverness, however, was about the distance over which air transport really did provide a facility such as the railways could not possibly provide.

Dealing with Mr. Greig's question why Imperial Airways, Ltd., had adopted the large flying boat, the President suggested that if he had considered how one could handle a machine, of the weight of one of the new flying boats, fitted with wheels on aerodromes such as were likely to be available in the middle of Africa in any sort of weather conditions, one reason would be apparent. There were also questions such as the differences between the costs of fuel in the middle of Africa and at the coast, which would appear to be rather important.

The reference, by Mr. Woods Humphrey, to speed as being a very expensive luxury had been quoted with approval by Mr. Greig; and although perhaps speed is being attained to-day with rather less financial extravagance than at one time had seemed likely from technical considerations, the President pointed out that the attainment of very high speeds brought the problem of noise into greater prominence. He was not so much worried by the increased danger arising from the attainment of very high speeds, although there was something in that. The earlier Imperial Airways machines that were used on the Paris service were noisy; but when the large Handley Page machines were introduced the contrast was extraordinary, for the latter machines were delightful and what may be termed the " cotton-wool era " seemed to have passed. He hoped, however, that the attainment of the increased speeds which the public demanded would not lead to the re-introduction of that era. His reason for that remark was that, although propellers and engines could be made reasonably silent at the cost of some complexity, the noise due to the wind rushing past aerodynamic surfaces increased very rapidly with speed; for the present, at any rate, there were no known means of diminishing that noise, which in the very high speed machines of to-day was comparable with the other two sources of noises he had mentioned.

Reply to the Discussion.

Dealing first with the President's comment on the prospect of flying from London to Edinburgh and arriving at the latter city at three o'clock in the morning, the journey occupying $3\frac{1}{2}$ hours, he said that few people, if any, would wish to commence such a journey late at night and to complete it at the time mentioned. When he had referred to such a journey, in the paper, he had had in mind the needs of a business man, for example, who could leave his office fairly early in the afternoon and complete such a journey before dinner.

He had specifically excluded Imperial Airways operations from the scope of the paper because those operations introduced such complexities. He was definitely aware of some of the reasons why Imperial Airways had adopted the use of large flying boats. For example, there were to a large extent sheltered waters on the Imperial routes, a fact which rendered the use of flying boats economically desirable; fuel costs must be substantially lower at the seaboard than inland; and the costs of maintenance of inland aerodromes, particularly bearing in mind the occurrence of monsoons from time to time and the softness of the ground surfaces under such conditions, must involve almost astronomical figures. One could appreciate a good many reasons for the use of flying boats on such services. But in the paper he had been referring to internal air line operation, and had borne in mind the fact that around the British Isles there were few sheltered waters.

Replying to Major Mealing, he said he had not included detailed economics in his paper because they would have occupied a great deal of time and space and at the same time would have been horribly misleading, because the Jersey Company's conditions of operation were radically different from the normal conditions of operation and the lessons to be learned from them were radically different.

With regard to the suggestion that insufficient attention was given to passengers individually, Mr. Greig said he had emphasised in the paper that the passenger should be caused the least possible mental disturbance during his journey. In other words, the passenger was a creature of habit, not of intelligence, and unless he were nursed from one end of the journey to the other he would not again travel by air. Many of the arguments concerning air travel were founded on the fallacy that people wanted to fly; but apart from a few fanatics, etc., people did not want to fly unless there were some definite attraction, their sole purpose being to travel from one point to another as quickly or as conveniently as possible. Air travel was not so comfortable as first-class rail travel, and it frightened some of them rather badly if they knew nothing about it—perhaps it frightened them even more if they *did* know something about it. To date, his company had carried 70,000 passengers; he had to listen to their growls and grumbles, and the one thing they detested more than anything else was to be left to find their own way to the airport. The company had been compelled to provide ground transport in certain cases where they would have preferred to have left it severely alone. After all, 70,000 passengers could not all be wrong!

The ideal machine for internal routes which involved sea crossings was a land type of plane so designed that it would be able to float for an indefinite period if it were forced down on the water, and he believed that shortly a machine would be produced to meet that requirement. It was important that it should be produced at reasonable cost. In that connection he referred to the Douglas machine which had sunk in Salt Lake; there had been no collapse of the structure, and it was reasonable to suppose that had it been divided into watertight compartments its displacement would have kept it afloat indefinitely. The speed of landing was not such as to smash the machine; therefore, there seemed no reason to adopt a composite flying-boat-land-plane design, for all that was necessary was to make a land plane watertight, and he saw no reason why that should not be done at reasonable cost.

In considering air line operation it would not do to disregard the time spent on ground transport to the aerodrome, as suggested by Mr. Hollis Williams. A man who was going to pay for transport was accustomed to think in terms of getting from point A to point B, and he would persist in thinking in those terms. Unless he happened to live near the aerodrome he had to use some form of ground transport and it was more than likely that he would travel via the very railway station from which the air line operators were going to carry him. The passengers must be looked after; but large-scale air line operators could not afford to send cars to collect passengers from places all over England when there were perhaps 70 or 80 people going out from one airport. Air transport must be regarded as a practical means of transport between points of departure and arrival to which the passengers were accustomed. Passengers to and from Jersey were accustomed to think of Southampton, and the Jersey Company had found it necessary to operate from Southampton.

Although the statisticians were accustomed to say that if the machines were operated at certain times the costs would be so much, and if they were operated at certain other times the costs would be so much, they seemed to forget that perhaps the members of the public did not wish to travel at the " other " times, and that if the operators insisted upon operating at those " other " times they might have to operate empty machines. The general public moved in droves and herds at certain times of the day, and even if aeroplanes were available at intervals of ten minutes the public would still want to crowd on to one. Naturally,

none of them wanted to travel at lunch time. Consider, for example, the point of view of a man who was perhaps going to fly for the first time and was somewhat alarmed by the prospect, imagining that he would be air-sick—as probably he would be! Would that man go to the trouble of breaking his habits of transport unless everything just happened to suit his convenience, and would he and others arrange their itineraries in such a way that the demand for the travel facilities would be spread over a considerable portion of the day, for the convenience of the operators? The fact was that certain times of the day suited the requirements of the majority of people. It was easy to say that 500 flying hours per annum would involve a certain cost and that 1,500 flying hours per annum would involve a certain cost; but unless the public convenience were studied the number of passengers to be carried might decrease by 25 per cent., which was a very serious matter. If the fares were to be competitive with those of surface transport one must reckon on an average load factor of at least 50 per cent.; that would cover costs of operation, without showing a profit.

When referring to Imperial Airways and average loading he had had in mind that they were still in the happy position of having a very substantial excess of demand over supply, the result of which was that, although there were traffic peaks, there were not violent fluctuations of anything up to fifteen times the minimum demand. So far they had only begun to scratch the surface of such traffic and were still able to pick and choose; but the potential traffic on Empire routes was vast, and 10 or 15 years hence the situation would be rather different from that of to-day. They might arrive at some unit of, say, 50 or 100 passengers, as the biggest units that could be adopted without having large sections of the fleet immobilised or flying empty.

The problem of speed *versus* comfort would depend largely upon the particular services under consideration. If passengers, to whom two competitive services were available, had to consider a flight of three hours' duration in comfort as against two and a half or two hours' flight in only moderate comfort, and assuming that fares were equal, it was probable that the speed consideration would win. There was no reason why the fares should not be about equal; indeed, if there were any difference at all in costs of operation, the faster machines would probably prove the more expensive on account of the percentage of time wasted on the ground. If, on the other hand, passengers had the choice of a flight of one and half hours in comfort as against a flight of one hour in less comfort, the consideration of comfort would probably win. Again, for flights of more than three hours, comfort would probably win. If a passenger had to consider five hours' flight in a fast machine against eight hours' flight in a comfortable machine, the comfortable machine would win every time. The average individual would tolerate travelling for an hour; after one and half hours he began to get annoyed and in three hours he was bored to tears. If he were uncomfortable as well it was just too bad!

With regard to types of aircraft, Mr. Greig said he did not subscribe to the view that the aircraft manufacturers were impossible, ridiculous and inefficient. Theoretically there should be a completely different design of aeroplane for each individual air route; but that was manifestly absurd in practice. An aeroplane which could be operated with reasonable efficiency upon any one of four or five categories of route, though it would not fulfil all the functions on all of those routes with 100 per cent. efficiency, was a good aeroplane. It was of no use grumbling at aircraft designers for not having produced the machine which would exactly fit a particular job. One should grumble at the designers, however, when they omitted the refinements which made all the difference between real usefulness and nuisance. In that connection he mentioned the placing of ventilators as an example. An operator might have a number of machines having different cabin furnishing systems and different seating capacities, and in only one type would the ventilators be placed intelligently; in the others they would be so placed that the draught would blow down the necks of the passengers, or would be placed

anywhere other than where they ought to be. That was a minor irritant which the manufacturers might well put right. There were also maintenance troubles arising from lack of forethought in design. It would be an excellent thing if every manufacturer had to take his aeroplane to pieces and put it together again, using the tool kit which he provided with the aeroplane; it would provide a useful lesson in the art of making things accessible. Similarly, he would learn a useful lesson if he were asked to inspect an aeroplane, after it had been flying for 100 hours without inspection, and if he were fined heavily for every indication of deterioration that he had failed to notice. Aeroplanes would then become really accessible!

The problem of maintenance of schedules, of course, was a function of the length of the air routes concerned; a certain variation in schedule could be tolerated, the degree of variation depending on the particular conditions. The percentage of variation permissible became lower as the route became longer, so that on the longer routes the margin of air speed available must be greater in order to keep within the permissible variation in schedule.

The provision of a service " every hour and on the hour " sounded very well, but the frequency must depend on the public demand. On short ferry services, for instance, there were heavy demands occuring at irregular intervals throughout the day, calling for high frequency, just as in the case of the London Underground Railway system. It must be borne in mind also that whereas a train could be operated at a very small load factor and still cover its costs, an aeroplane could not. The American air lines which were quoted so frequently as being paragons of efficiency were certainly very efficient from the technical and economic standpoints; but he would hate to have to pay their losses every year! He did not consider that any operation which was founded on a subsidy—and an uneconomic mail contract was a concealed subsidy—was legitimate operation. It should be founded only on plain, solid business. The difference between the outlooks of American and British citizens was another factor to be borne in mind. An American would fly because he was always very pleased if he could save even 10 minutes; whether he made use of that 10 minutes or whether he did not was a matter which did not seem to bother him. In this country, however, we had rather different ideas, and rather wanted to see something for our money.

With regard to bookings for air passages, Mr. Greig said he was in the happy position of sitting on both sides of the fence simultaneously. The Jersey Company had commenced operations without any booking facilities beyond those which they had created themselves; they had had about four agents. In the first year they had carried 19,000 passengers, the reason being simply that the service was of practical utility to the travelling public. The rate of development of the service had been almost exactly a function of the number of personal recommendations. Nowadays quite a number of booking agents were assisting, but such publicity as had been given to the service and such assistance as the agents were giving, although very valuable, had not accelerated the natural growth of the traffic as much as might have been supposed. The greatest factor seemed to have been personal recommendations.

As to day *versus* night flying, he said that during the day, if something went wrong or if the weather began to close down, there was a reasonable chance of making a forced landing without doing any serious damage. On the other hand, apart from the fact that radio had a nasty habit of playing tricks at night, the chances of making a successful forced landing after dark were not good enough, and there was not such an over-supply of pilots that the country could afford to have them killed off rapidly. He was not in favour of asking pilots to fly anywhere if he were not willing to accompany them. Night services could not be operated on regular schedules with a high degree of reliability—something over 95 per cent. maintenance of schedules was definitely indicated—until machines were able to land with certainty at their destinations, in all but the most outrageous conditions, and without producing a nervous breakdown on the part of the

pilots. We could not do that yet. Even Imperial Airways and the Continental air lines, which put up an astoundingly good show, did not profess to put up a very high standard at night in all weathers, especially under conditions such as were encountered in the north, where most of the night flying would have to be done. He did not think they would attempt to do it; and if they did attempt it they would be the first to admit that the degree of risk was higher than that to which their present passenger traffic was exposed.

In his reference to the training of air traffic staffs he had had in mind the fact that those who had been engaged previously in handling surface traffic, such as railways and shipping, seemed to have developed certain fixed habits and to have become obsessed with the idea that they knew something about handling all traffic. The handling of air traffic, however, developed a different mentality, for the factors to be dealt with were different from those applying to surface transport. There were many individuals who were likely to become highly efficient air traffic officers in spite of their previous training in ground transport rather than because of it. In connection with air traffic it was necessary to think in terms of weight as well as in terms of seats, and it seemed to be quite foreign to the ideas of an ordinary shipping or railway clerk to think in terms of weight.

Emphasising that public support of an air line was dependent upon the public utility of that air line, he said that the public placed safety first, and comfort was a very close second; further, they liked to see value for their money, and did not like paying more for air travel than for other forms of travel. He would love to be able to arrange that passengers could merely buy a ticket in a slot machine in order to travel by air; but so long as operators were tied down by things such as load sheets, or so long as they were tied to aircraft which must be loaded to a 50 per cent. load factor if it were to cover costs of operation, it would be necessary to write down the passengers' names so that their seats could be reserved. The work of seat reservation must be carried out with a very high degree of efficiency indeed in order to keep the load factors anything like reasonable. Operators had also to observe Air Ministry Regulations, and there were all sorts of other difficulties.

Referring again to subsidies, he said that anything founded on the shifting sands of a Government decision was a very bad economic proposition. For example, in America there had been some very beautiful air mail contracts at very beautiful rates, but in the course of an economy drive those contracts had been cancelled. The public did not do that sort of thing. It might take a long time to persuade the public to support an air line, but when they had given their support they would not all withdraw it at once, unless the air line operators did something outrageously stupid. He added that subsidies opened the door to red tape and inefficiency.

Finally, Mr. Greig said it was a definite fact that we could not hope to offer air transport, at its present stage, at the same fares as third-class rail transport, and we should be doing extremely well if we could offer it at the same fares as first-class rail.

At the conclusion of the meeting a hearty vote of thanks was accorded Mr. Greig for his paper and for his reply to the discussion.

SUMMARY OF THE SOCIETY'S ACTIVITIES

DECEMBER, 1935—DECEMBER, 1936.

The following places on permanent record in the Journal the notices which have appeared in the Monthly Notices inset in the Journal and so summarises the activities of the Society for the year. Activities not reported in the Summary will be given in the Annual Report of the Council which will be published in the Journal for March, 1937.

COUNCIL AND OFFICERS, 1936-1937.

President:

Mr. H. E. Wimperis, C.B., C.B.E., M.A., M.I.E.E., F.R.Ae.S.

Past-President:

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P.

Vice-Presidents:

Mr. F. Handley Page, C.B.E., F.R.Ae.S.
Major T. M. Barlow, M.Sc. (Eng.), M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.

Council:

Captain P. D. Acland.
Major J. S. Buchanan, C.B.E., A.M.I.Mech.E., F.R.Ae.S.
Major G. P. Bulman, O.B.E., B.Sc., M.I.A.S., F.R.Ae.S.
Mr. H. Roxbee Cox, Ph.D., D.I.C., B.Sc., F.R.Ae.S.
Mr. A. H. R. Fedden, M.B.E., M.I.A.E., M.S.A.E. F.R.Ae.S.
Mr. A. Gouge, B.Sc., F.R.Ae.S.
Professor F. T. Hill, F.R.Ae.S., M.I.Ae.E.
Professor G. T. R. Hill, M.C., M.Sc., F.R.Ae.S.
Captain A. G. Lamplugh, F.R.Ae.S., M.I.Ae.E., F.R.G.S.
Mr. W. O. Manning, F.R.Ae.S.
Major R. H. Mayo, O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S.
Mr. R. J. Mitchell, C.B.E., Assoc.M.Inst.C.E., F.R.Ae.S.
Dr. N. A. V. Piercy, M.Inst.C.E., M.I.Mech.E., F.R.Ae.S., M.Cons.E.
Professor A. J. Sutton Pippard, M.B.E., D.Sc., M.Inst.C.E., F.R.Ae.S.
Lord Sempill, A.F.C., F.R.Ae.S.
Mr. O. E. Simmonds, M.A., F.R.Ae.S., M.I.Ae.E., M.P.
Mr. C. C. Walker, Assoc.M.Inst.C.E., F.R.Ae.S.

Honorary Treasurer:

Major D. H. Kennedy, O.B.E., F.R.Ae.S.

Solicitor:

Mr. Lawrence A. Wingfield, M.C., D.F.C., A.R.Ae.S.I.

Honorary Librarian:

Mr. J. E. Hodgson, Hon. F.R.Ae.S.

Honorary Accountant:

Mr. A. N. D. Smith, F.C.A.

Secretary and Editor:

Captain J. Laurence Pritchard, Hon. F.R.Ae.S., A.F.I.Ae.S.

COMMITTEES OF COUNCIL.

The following Committees of Council were appointed for 1936-1937 :—

Amulree Committee:

Lord Amulree, Professor L. Bairstow, Mr. Griffith Brewer, Mr. C. R. Fairey, Lord Gorell, Major D. H. Kennedy, Lord Mottistone, Lord Sempill and Mr. H. E. Wimperis.

Development Committee.

Major J. S. Buchanan (Chairman), Mr. C. R. Fairey, Mr. F. Handley Page, Sir John Siddeley, Mr. H. E. Wimperis and Major D. H. Kennedy (*ex officio*).

Education and Examinations Committee:

Professor G. T. R. Hill (Chairman), Mr. H. Roxbee Cox, Mr. S. H. Evans, Professor F. T. Hill, Mr. M. Langley, Mr. W. M. Page, Dr. N. A. V. Piercy, Mr. D. R. Pye, Mr. W. P. Savage.

Finance Committee:

Major D. H. Kennedy (Honorary Treasurer and Chairman), Captain P. D. Acland, Major T. M. Barlow, Mr. Griffith Brewer, Major J. C. Buchanan, Mr. H. Burroughes, Mr. E. C. Gordon England, Professor F. T. Hill, Mr. J. E. Hodgson (Honorary Librarian), Captain A. G. Lamplugh, Mr. F. Handley Page, Mr. F. R. Simms, Mr. A. N. D. Smith (Honorary Accountant) and Mr. L. A. Wingfield (Solicitor).

Grading Committee:

Captain F. S. Barnwell, Mr. R. A. Bruce, Major G. P. Bulman, Major F. A. Bumpus, Mr. W. S. Farren, Lieut.-Colonel L. F. R. Fell, Mr. A. Gouge, Professor F. T. Hill, Mr. R. J. Mitchell, Mr. W. P. Savage, Lord Sempill, Professor R. V. Southwell, Dr. H. C. Watts.

Lectures Committee:

Major R. H. Mayo (Chairman), Major G. P. Bulman, Mr. R. S. Capon, Mr. M. Langley, Mr. W. O. Manning, Mr. D. R. Pye, Mr. S. Scott-Hall, Mr. C. C. Walker.

Medals and Awards Committee:

Mr. H. E. Wimperis (Chairman), Mr. Griffith Brewer, Sir Robert Brooke-Popham, Major J. S. Buchanan, Mr. A. H. R. Fedden, Mr. A. Gouge, Group Captain G. B. Hynes, Mr. W. O. Manning, Sir A. Verdon Roe, Mr. G. R. Volkert, Mr. C. C. Walker and Mr. L. A. Wingfield (Solicitor).

Rules Sub-Committee:

Professor L. Bairstow, Mr. Griffith Brewer, Mr. A. H. Hall, Major D. H. Kennedy (Honorary Treasurer), Mr. W. O. Manning, Lord Sempill, Mr. L. A. Wingfield (Solicitor).

REPRESENTATIVES ON OTHER BODIES.

Advisory Committee for Aeronautical Engineering of the City and Guilds of London Institute: Professor F. T. Hill and Captain J. L. Pritchard.

Advisory Council of the Science Museum: Lord Sempill.

Air League of the British Empire: Mr. W. O. Manning and Mr. Griffith Brewer

Association of Special Libraries and Information Bureaux: Mr. J. E. Hodgson (Honorary Librarian).

British Corporation Register of Shipping and Aircraft, Aviation Committee: Lord Sempill.

British Gliding Association: Council: Mr. W. O. Manning.
Technical Committee: Captain J. L. Pritchard, Professor F. T. Hill.

British Standards Institution, Aircraft Committee: Major R. H. Mayo and Dr. H. C. Watts.

British Standards Institution, Committee on Symbols and Abbreviations Used in Engineering: Major A. R. Low.

British Standards Institution Technical Committee on Aircraft Nomenclature: Professor L. Bairstow, Captain J. Laurence Pritchard.

Engineering Joint Council: Mr. C. R. Fairey.

Special Educational Representative: Major T. M. Barlow.

The Guild of Air Pilots and Air Navigators of the British Empire, Sefton Brancker Memorial Fund Committee: Captain P. D. Acland.

Joint Standing Committee with the Society of British Aircraft Constructors and the Royal Aero Club: Professor L. Bairstow, Lord Sempill, Lieut.-Colonel J. T. C. Moore-Brabazon.

Lloyds Aviation Committee: Lieut.-Colonel J. T. C. Moore-Brabazon.

National Central Library: Mr. J. E. Hodgson (Honorary Librarian).

Seagrave Memorial Fund Committee: Mr. C. R. Fairey.

Students' Section: Mr. J. C. Hardman (Honorary Secretary).

ANNUAL GENERAL MEETING.

The Annual General Meeting of the Society was held on Monday, March 30th, 1936, in the Library, at 7, Albemarle Street, London, W.1, at 6.30 p.m.

Present:

Lieut.-Col. J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P. (President), in the chair.

Gerald Bonnaud (Companion).
The Hon. Alan Boyle (A.F.).
Major G. P. Bulman (Fellow).
J. D. Campbell (A.F.).
R. S. Capon (Fellow).
H. R. Carefoot (A.F.).
Miss L. Chitty (Fellow).
H. Roxbee Cox (A.F.).
S. H. Evans (M. and A.F.).
E. G. Fischeles (A.F.).
S. Scott-Hall (A.F.).
Professor F. T. Hill (Fellow and Member).
C. H. Jackson (Student).
Miss A. Kennedy (Companion).
H. Leaderman (Student).
W. O. Manning (Fellow).
P. P. Nazir (A.F.).
Sqdrn. Ldr. F. A. Norton (Member).
Dr. N. A. V. Piercy (Fellow).
Flt. Lt. R. C. Preston (A.M.).
D. R. Pye (Fellow).
W. P. Savage (Fellow).
J. E. Sloan (Associate).
H. E. Wimperis (Fellow).

Captain J. Laurence Pritchard (Secretary).

1. The Secretary read the notice convening the Meeting.

2. The President asked the indulgence of the meeting in altering the order of the items on the Agenda as he would have to leave the meeting early owing to an important engagement at the House of Commons. He would ask the Vice-President, Mr. H. E. Wimperis to preside during the latter part of the meeting.

The first item on the Agenda was to appoint Scrutineers for the Council Ballot. In past years, this involved the absence of those scrutineers from the Annual General Meeting. The President considered it would be a more satisfactory arrangement if the ballot could be dealt with, say, on the afternoon of the Annual General Meeting. This would involve a change in the Rules for which a Special General Meeting would have to be called.

It was proposed by Mr. W. O. Manning and seconded by Mr. R. S. Capon that the Council be asked to consider a more convenient method for scrutinising ballot papers than that at present in force.

3. The President said he presumed that the Annual Report and Accounts published in the March, 1936, Journal had been read by all those present. This was an occasion on which opinions and criticisms thereon could be aired.

The President considered that the most important item now in progress was the question of the Society's own building. There was a possibility of the Society taking its place among other important engineering institutions in possessing a building which housed a library, lecture theatre, and the secretariat. The Finance Committee were considering a possible scheme and when the proposition had progressed further, the members would be consulted for their opinion.

It was announced that the Wilbur Wright Lecture would be delivered this year by Mr. D. R. Pye, M.A., M.I.Mech.E., F.R.Ae.S., on " Slippery Surfaces."

The President considered the Reports from the branches were satisfactory.

It was regretted that the Chairman of the Finance Committee was unable to be present to deal with any questions raised on the financial position of the Society. The President pointed out, however, that although the Income and Expenditure Account showed a deficit the position was not so unsatisfactory as it appeared.

The Annual Report and Accounts were then passed.

4. It was proposed by Mr. H. E. Wimperis and seconded by Mr. W. O. Manning that Messrs. Price, Waterhouse and Co. be re-appointed as Auditors for the ensuing year for Aerial Science Limited and Aeronautical Trusts Limited.

5. The following members were appointed as Scrutineers of the Council Ballot :—

Flt. Lt. R. C. Preston (A.M.).
The Hon. Alan Boyle (A.F.).
Miss A. Kennedy (Companion).
Mr. D. R. Pye (Fellow).
Miss L. Chitty (Fellow).
Dr. N. A. V. Piercy (Fellow).
Mr. J. D. Campbell (A.F.).

Before calling upon the Scrutineers to commence the counting, the President said he would like to say a few words to those members present. This would be the last occasion on which he would preside over an Annual General Meeting of the Royal Aeronautical Society as under the Rules he would be called upon to retire this year and stand down for one year at least. The President said he would like to take this opportunity of thanking the Council and members for the consideration and help he had received during his term of Presidency. He considered the position of President of the Society was the highest honour which could be awarded in aeronautics. He had thoroughly enjoyed every minute of his service.

He would like to thank the Council for their help and especially Captain Pritchard, the Secretary, for the loyalty and understanding he had shown.

He wished the Society every success.

The President then called upon the Scrutineers, and asked Mr. H. E. Wimperis (Vice-President) to continue in the chair as he had to leave the meeting.

The Vice-President then took the chair.

6. The Vice-President announced that Mr. Roxbee Cox had a suggestion to put before the meeting before the Scrutineers left the room.

Mr. Roxbee Cox outlined a discussion he had had recently with senior members of the Students' Section on the question of the introduction of a new grade of membership. It was suggested that members in the new grade would have qualifications intermediate between the qualifications required in Students and those required in Associate Fellows or Associate Members, and would be known as Graduates. It was suggested that a new rule be considered by the Council for submission to a General Meeting as follows:—

> "A Graduate shall be a person not under 21 years or over 26 years of age, who has passed the Associate Fellowship or Associate Membership

Examination or such other exempting examination as may be approved from time to time by the Council, and has satisfied the Council that he has received or is receiving sufficient such regular training in aeronautics as to fit him to become an Associate Fellow or Associate Member."

Mr. Roxbee Cox pointed out that there was no novelty in the suggestion. Other learned Societies have a Graduate Grade.

The Vice-President said the meeting had heard Mr. Roxbee Cox's proposal and the matter was open for discussion.

Mr. Capon said he presumed the age limit would be 26.

Mr. Roxbee Cox said that was the proposed age limit.

Mr. Manning pointed out that other Societies had Students and Associates as well.

The Vice-President presumed the Council would be guided by precedent of other Institutions.

Mr. Manning suggested the Council be asked formally to consider the question.

The Vice-President said this was an opportunity for the members to oppose the suggestion if they wished.

Mr. Manning proposed and Dr. Piercy seconded that the Council be asked to look into the matter and act on it as they think fit.

Mr. Evans said he thought that procedure would put the matter back for a year.

The Vice-President said there will probably be a Special General Meeting to consider the proposal together with the suggested change in the Rules with regard to the counting of the Council ballot as outlined by the President at the commencement of the meeting.

The proposal was then put to the meeting and passed.

The Scrutineers then left the room for the Council ballot.

Mr. G. Fischeles asked if some concession with regard to Entrance Fees could be made to Students transferring to higher grades.

Mr. Savage pointed out that the payment of entrance fees was only deferred.

Professor F. T. Hill said everybody looked with sympathy on the general idea, but he would agree with Mr. Savage that the entrance fee is only deferred and he considered everybody should pay an entrance fee.

The Vice-President suggested the Secretary should be asked to ascertain from other Institutions what is their procedure.

The Vice-President asked those members left in the room to discuss any matters relating to the Society, while the Council ballot was being counted.

Mr. Manning suggested that it was a good opportunity for members to make suggestions for lectures for next Session, and a number of suggestions were made for consideration by the Lectures Committee.

7. The Scrutineers of the Council Ballot presented their report resulting in the election to the Council of the following candidates:—

A. H. R. Fedden (Fellow).
A. Gouge (Fellow).
F. T. Hill (Fellow and Member).
W. O. Manning (Fellow).
R. J. Mitchell (Fellow).
F. Handley Page (Fellow).
A. J. Sutton Pippard (Fellow).
Lord Sempill (Fellow).
C. C. Walker (Fellow).
H. E. Wimperis (Fellow).

The meeting closed with a vote of thanks to the Scrutineers.

ADDRESS TO H.M. KING EDWARD VIII.

The following address, signed by the President of the Society, was forwarded to H.M. the King on the occasion of his Accession to the Throne:—

TO HIS MAJESTY KING EDWARD VIII, OF THE UNITED KINGDOM OF GREAT BRITAIN, IRELAND AND OF THE BRITISH DOMINIONS BEYOND THE SEAS, DEFENDER OF THE FAITH, EMPEROR OF INDIA.

May it please Your Majesty, We, your most dutiful and Loyal Subjects, the President, Council, and Members of the Royal Aeronautical Society of Great Britain, beg leave humbly to offer our condolence to Your Majesty on the great sorrow you have sustained in the death of our beloved Sovereign, the late King, and respectfully to assure you of our unswerving loyalty and devotion to Your Majesty's person.

ELECTION OF PRESIDENT.

Mr. H. E. Wimperis, C.B., C.B.E., M.A., M.I.E.E., F.R.Ae.S., Director of Scientific Research at the Air Ministry, was elected President of the Society for the year 1936-1937, at the Council Meeting held on May 12th, 1936.

ELECTION OF VICE-PRESIDENTS.

The following were elected Vice-Presidents of the Society for the year 1936-1937, at the Council Meeting held on May 12th, 1936:—

Major T. M. Barlow, M.Sc. (Eng.), M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.
Mr. F. Handley Page, C.B.E., F.R.Ae.S.

NEW YEAR HONOURS.

Viscount.

Marshal of the Royal Air Force Hugh Montague Baron Trenchard, G.C.B., G.C.V.O., D.S.O., D.C.L., LL.D. (Honorary Fellow).

Knight.

Lieut.-Colonel Francis Claude Shelmerdine, C.I.E., O.B.E. (Fellow).

C.B. (Military Division).

Air Vice-Marshal Henry Meyrick Cave-Browne-Cave, D.S.O., D.F.C. (Fellow).

Air Commodore Napier John Gill, C.B.E., M.C. (Associate Fellow).

O.B.E.

Herbert Lawrence Stevens, Esq. (Fellow).

KING'S BIRTHDAY HONOURS.

Royal Victorian Order.

G.C.V.O.—Viscount Charles C. Wakefield, C.B.E.

Viscount Wakefield is an Honorary Fellow of the Society.

ELECTIONS.

On December 10th, 1935:—

Fellow.—Magnus Herman Volk (from Associate Fellow).

Associate Fellows.—Charles Moberly Barter, Bernard Arthur Duncan, Clifford Moore.

Associate Member.—Robert Walter.

Associates.—Richard Cox Abel, Cyril Henry Arthur Colman, Charles Brian Field.

Students.—John Leonard Burbidge, Karl Antony de Lisser, Kenneth Raymond Dixon, Henry Charles Horton Gurney, Thomas Anderson Jones, Kyoichi Nosawa, Henry Ernest James Rochfort, Ernest Edwin Robertson, Frank Tyson.

Companion.—Gerald Bonnaud.

On January 21st, 1936:—

Fellows.—A. Francis Arcier, Harold John Pollard, Bernard William Shilson.

Associate Fellows.—Herbert Reginald Carefoot, Roger Lander Ninnes, Edwin Shipley, Herbert Brian Squire, James William Philip Uren, Alfred Richard Weyl, Howard Arthur Wills.

Associate Members.—Esmond Brown, F. G. Boreham, William Goodridge, Jai Singh.

Associates.—William Courtenay, G. C. Datta, Reginald Ernest Gustine, R. C. Manocha, G. W. Nunn, J. J. E. Sloan, Nigel Tangye.

Students.—C. G. Allington, William Armstrong, H. J. Campton, David Gilbert, M. H. Gordon, Miss B. Etty Leal, Edward John Mann, G. E. Marshall, W. J. Morton, C. J. Titler, D. D. Fenton Smith, J. A. C. Williams, G. E. L. Wray, A. D. Young.

Companions.—J. B. Bayas, M. G. Casey, S. J. Davies, W. M. Mackinlay, M. K. Paranjpye.

On February 11th, 1936:—

Fellow.—William Donald Douglas.

Associate Fellows.—Luis de Florez, Howard Trethewen Edgecombe, Geoffrey Fraser Wallace.

Associate Members.—George Frederick Halliday, James Victor Saunders.

Associates.—Ralph Charles Pike, Alexander Symon, Percival Nesbit Willoughby.

Students.—John Dennis Graham, William Alan Kenneth Grant, Denys Marsh Gulliver-Cradwick, John Hardenberg, William Jackson, Robert Dove Leakey, George Noel Fraser Luckie, Alfred Lipfriend, William John Adams Luscombe, H. A. Skeats, K. M. Smith, Maung Kyaw Tha, Peter Clarkson Wise.

Companions.—Miss Alice Kennedy, James Leonard Barnard Jones.

On March 10th, 1936:—

Fellow.—Walter Potter Savage (from Associate Fellow).

Associate Fellows.—Edward George Fischeles (from Student), Eric Pyke, David Llewelyn Ellis, Thomas Swinden, James Alfred Wells.

Associates.—Abdul Khan Majeed, Charles Harry Smith, Walter Noble Twelvetrees, Charles James Walker, Ronald John Knights-Whittome (from Student).

Students.—Kenneth Alfred Mackay Baldry, Victor Brussovansky, John Noel Graydon-Carter, Jayaram Dayaram, Imrie Dodd, Harold Michael Gardiner, Hugh McLennan Kendall, John Lansdell, Derek Charles Palmer, Gordon Ernest Rose, Edgar Allen Stroud, Donald Crawford Wood.

Companions.—John Bingham Emmott, Colin James Craig Ewing (from Student), John Parkyn Jeffcock.

On April 21st, 1936:—

Fellows.—Harold Roxbee Cox, Gustav Victor Lachmann.

Associate Fellows.—Roland Henry Chaplin, Donald McCorquodale, George Wilfrid Mullett, Sigurd Oswald Norman, Robert Randolph Osborn, Reuben Jacob Schmidt, George Sidney Selman, Sidney Youngman Smith, W. Lawrence Tweedie.

Associate Members.—John James Carroll, Thomas Redford Harms, Albert Frederick Johnson, Ernest Arthur Harrop, Walter Lennard Lax, Frederick James Oldland.

Associates.—Robert Perry, William Harold Primrose, Nariman Rustomjee, Gilbert Owen Waters.

Students.—Ronald Geoffrey Anderson, Edward Tranter Barber, Terence David Brian Blake, Maurice Joseph Brennan, Martin Cahill, Patrick Edward Chaundy, Edmund Ray Cooper, John Sterndale Scott Cox, Terence Edward Gouvenot Gardiner, Raymond William Gibbs, Gordon Kenneth Luker Gourlay, Kenneth Alfred John Knell, Roger Ashton Eckford Luard, Peter Gordon Masefield, Claude Reginald Thomas Matthews, Morien Bedford Morgan, Anthony Owen, William Henry Stephens.

Companions.—Marcus Goodall, Alastair Renoldson Ross.

On May 12th, 1936:—

Associate Fellow.—Roy Francis Highett.

Associates.—Erich C. A. Backhaus, Frank E. Buckell, Francis Otto Dorer, Ronald Clifford Hockey, Edward James Kirby, Andrew Auberon Peebles, Geoffrey Temple Perkins.

Students.—Cyril George Buxton, Edward A. George Chlala, Albert R. Crocker, Francis Jeffrey Ireland, Johan Nicolaas Maas, Max Wender, Francis Richard Wilbraham.

On June 9th, 1936:—

Member.—Alfred Charles Morris Jackaman.

Associate Fellows.—Christopher Ainsworth Davis, Frederic Wyndham Freke Hewitt, Clifford Hirst Jackson, Paul Goudime-Levkovitsch.

Associate Members.—James John Brand, Richard Ernest Drake, George Humphrey Winn.

Associates.—Shiu Parkash Kathuria, John Grimmond Gunn.

Students.—Harry Edward Adams, Peter Alan Lantsbery Grear, James Joseph Browne Houston, Robert Miller, Stanley Robert Parker, Douglas Carl Stewart, Mervyn Millington Waghorn, George Herbert Westlake, John Rayner White.

Companions.—D. J. L. Cowan, George Fred Parkhurst Trubridge.

On September 15th, 1936:—

Fellow.—Harold James Penrose (from Associate Fellow).

Associate Fellows.—Wilfrid Evelyn Crook, Maurice Herrod-Hempsall (from Student), Harold Nichols Horne, Hugh Stuart Howat, Reginald Leach, Geoffrey Alexander McMillan (from Student), Glencairn Sholto Ogilvie (from Student), H.R.H. Prince Alvaro de Orleans-Borbon, Alexander Robert Wright (from Companion), Stephen Joseph Zand.

Associate Members.—George Carter, Edward Wood Dodds, John Butler Harris, Charles Idrys Kidston, Albert Henry Lawrence, Robert Charles Morgan (from Associate), Harold Parkinson (from Associate), Harold George Winton.

Associates.—Sydney Arthur Claude Baker, Graves Patrick Maxwell Eves, Henry Arthur Fowler-Tutt, Sydney Charles Hart-Still, Edward Lumley Delpratt White, George Humphrey Winn.

Students.—Leslie Richard Eyre Appleton, Philip Alfred Barber, Peter Charles Bromwich, Ralph Cuthbert Chisholm Brown, William Allison Hall Brown, Thomas Ignatius Burke, Walter Graham Clark, Donald Diamond, Denis Pierpoint Edkins, Thomas Anthony Gawade, Arnold Alexander Hall, Frazer Apsley Harte, Harold Henry Hopkins, Norman Hugh John Johnson, James William Kenny, Cameron Frederick Mervyn-Jones, Terence Macrae Myles, Lyman Manary Nesbitt, Peter Alfred Henry Pooley, Roger Roach, John Edmund Roe, Norman Sandham, Sheldon Benton Smith, Ralph Francis Newman Swingler, Anant Vishnu Vartak, William Alfred Canning Weetman, Allen Craig Williams.

Companions.—Paul Howlett Campion, Hugh Stanley Ellis (from Student), James Hunter Farr, Arthur Drummond Williams Pimm, Patrick Ryan, Peter Shaw, Kwei-Jui Tai.

On October 20th, 1936:—

Fellows.—A. C. Kermode (from Associate Fellow).

Associate Fellows.—Robert Graham, E. T. Jones, P. McCormack, R. A. Shaw, A. J. Sidery, J. B. Taylor, J. I. Waddington, J. L. Watkins, D. B. Winter.

Associate Member.—R. Glynn Jones.

Associates.—C. G. K. Browne, E. W. La Borde, J. H. Millar, R. D. Stoner.

Students.—D. Cameron, A. V. Cleaver, H. Davies, D. R. H. Dickinson, L. T. B. Fenn, D. F. Fletcher, G. R. Forbes, W. A. Fowler, J. Halliwell, D. A. C. Harper, R. G. S. Hogarth, E. T. House, D. I. Husk, K. Kenney, A. V. Kilburn, Miss Sheila McGuffie, B.Sc., W. J. M. Moss, E. R. Owen, E. G. Pattison, G. A. A. Russell, C. H. Sworder, D. M. Ware, C. A. Wood-Collins.

Companions.—A. Gibbons, Harold Zettersten.

On November 10th, 1936:—

Associate Fellows.—Roland Frederic Bailey, L. Everett Baynes, James Allan Jamieson Bennett, David Wallace Bottle, Lawrence Percival Coombes, Michael Gerard Casey, Henry Peterson Fraser, John Percy Gott, Wilfrid Edmund Brailsford Hennesey, Cecil Edwin Kerr, John Harold Lees, Pietro Clemente Lombardini, Arthur Prescott, James Blackstone Taylor, Jnr.

Associates.—Anthony Bridgeman Gibbons, Peregrine Forbes Morant Fellowes.

Students.—Eric Sydney Allwright, Alfred Herbert Alwin Bastable, Arthur James Cowing, Harry Maurice Gallay, Arthur St. George Harris, Leighton Stuart Holt, Thomas Henry Lismer, Horace Michael Dermott Magil, Richard Vivian Peacock, Cecil Arnold Ridgewell, Gilbert Frederick William Roper, Ernest Alfred Sleigh, Albert George Smith, Norman Jesse Wadsworth.

Companions.—Paul Adorjan, Francis James Waters.

Associate Fellowship and Associate Membership Examinations.

The following candidates were successful at the December, 1935, examinations:

Associate Fellowship Examination.

L. G. Byrne	Theory of Internal Combustion Engines. Aircraft Materials.
H. A. Craw	Applied Mathematics. Theory of Internal Combustion Engines (1st Place). Aircraft Materials (1st Place).
W. E. Crook	Theory of Internal Combustion Engines. Wireless Telegraphy and Telephony.
A. H. Denny	Design (Aero Engines).
E. G. Gregson ...	Pure Mathematics (Commended). Strength of Materials and Structures. Aerodynamics (Commended).
N. Grossman	Applied Mathematics. Theory of Internal Combustion Engines. Design (Aero Engines).
J. C. Hardman ...	Strength of Materials and Structures.
V. A. M. Hunt ...	Applied Mathematics. Theory of Internal Combustion Engines. Aircraft Materials.
C. P. L. Nicholson ...	Aerodynamics.
P. N. Willoughby ...	Navigation and its Application to Aeronautics.

Associate Membership Examination.

P. H. Campton	Theory of Internal Combustion Engines. Aircraft Materials.
P. N. Cunningham ...	Applied Mathematics. Theory of Internal Combustion Engines. Aircraft Materials.
K. R. Dixon	Applied Mathematics. Theory of Internal Combustion Engines. Aircraft Materials.
E. O. Draper	Applied Mathematics. Theory of Internal Combustion Engines (1st Place). Aircraft Materials (1st Place, Commended).
J. D. Gordon	Theory of Internal Combustion Engines. Aircraft Materials.
M. H. Gordon... ...	Applied Mathematics. Theory of Internal Combustion Engines. Aircraft Materials.
H. T. Grigg	Applied Mathematics. Theory of Internal Combustion Engines. Aircraft Materials.
I. H. List	Applied Mathematics (Commended). Theory of Internal Combustion Engines. Aircraft Materials.
G. N. F. Luckie ...	Applied Mathematics (1st Place, Commended). Theory of Internal Combustion Engines. Aircraft Materials.

R. C. Morgan ...	Applied Mathematics. Strength of Materials and Structures.
G. P. L. Pardoe ...	Applied Mathematics. Theory of Internal Combustion Engines. Aircraft Materials.
R. L. Smyth	Applied Mathematics. Aircraft Materials.
M. K. Tha	Applied Mathematics. Theory of Internal Combustion Engines.

The following Candidates were successful at the examinations held in May, 1936:—

ASSOCIATE FELLOWSHIP.

L. G. Byrne	Applied Mathematics.
W. E. Crook	Applied Mathematics.
R. M. Helsdon ...	Aerodynamics. Design (Aircraft).
F. J. Horn	Strength of Aeronautical Materials and Structures. Aerodynamics.
D. Milne	Pure Mathematics.
L. W. Nethercott ...	Aircraft Materials.
A. D. W. Pimm ...	Strength of Aeronautical Materials and Structures. Aerodynamics.
E. J. C. Rayner ...	Pure Mathematics.
G. J. Thomson ...	Aerodynamics. Design (Aircraft).

ASSOCIATE MEMBERSHIP.

C. R. P. Bizeray ...	Pure Mathematics.
P. H. Campion ...	Applied Mathematics.
L. D. V. Edwards ...	Pure Mathematics. Aerodynamics.
R. Lindsay-Smyth ...	Theory of Internal Combustion Engines.
R. C. Morgan ...	Air Transport.
M. K. Tha	Aircraft Materials.
H. G. Winton ...	Applied Mathematics. Strength of Aeronautical Materials and Structures. Theory of Internal Combustion Engines.

WILBUR WRIGHT MEMORIAL LECTURE AND RECEPTION, MAY 21ST, 1936.

The 24th Wilbur Wright Memorial Lecture was delivered by Mr. D. R. Pye, M.A., M.I.Mech.E., F.R.Ae.S. A report is given in the October, 1936, Journal, page 747.

EXHIBITION AT THE SCIENCE MUSEUM.

By kind permission of the Director of the Science Museum, Colonel E. B. McKintosh, a special exhibition was shown in the Aeronautical Section of the Museum to mark the 70th anniversary of the founding of the Society. The exhibition was opened on the occasion of the Society's annual Reception on May 21st, immediately following the Wilbur Wright Memorial Lecture.

The President and Council wish particularly to place on record their appreciation of the help which was given by so many members of the Society and others to make the exhibition the great success it was, a success indeed which caused it to be extended for a further month, until July 22nd, during which time it was visited by a large number of people. The exhibition was arranged by the Honorary Librarian, Mr. J. E. Hodgson, Hon. Fellow, who lent largely from his own unique collection and to whom special thanks are due.

The exhibit was one of the most remarkable collections of aeronautical objets d'art, trophies, medals, engravings, stamps and rare or unique articles connected with ballooning and aviation yet shown publicly in this country.

Among the objects shown were the first aeronautical passport, issued to the famous balloonist Green for his crossing from London to Holland by air in 1836; a fifteenth century account of Alexander the Great and his flying eagles, one of the earliest printed references to flying; the rare coloured specification of Henson's aerial carriage of 1842, which led to the first flight of a power-driven model six years later—only two copies of this specification are known; the famous Schneider Trophy, won for all time by Great Britain; original letters, MSS. and drawings of Lunardi, Glaisher, Pilcher, Hargrave and other famous pioneers, including a collection of MSS. of Sir George Cayley with drawings of his glider originally designed in 1804; and the original Council Minutes of the Society, dated January 12th, 1866; plates and bowls, fans, snuff-boxes, vanity boxes, buttons and handkerchiefs, decorated with aeronautical subjects, and a unique collection of medals were among the items which made this exhibit one of absorbing interest and historical value.

The following is a list of the exhibits together with the names of those who lent them :—

Dr. Poynton.—Twenty-five books of historical interest, 15th-19th century; balloon fan; tea caddy belonging to James Sadler, the balloonist; balloon vanity boxes; French cardboard box decorated with Portevin's balloon; handkerchiefs of Henson's aerial steam carriage; pocket case with balloon decoration; porcelain drawer handles with balloon pictures; two balloon snuffboxes; seven balloon plates of Lambeth Delft ware; miniature of first aerial voyage; round box with Cocking's parachute and balloon; balloon tray; carved ivory horn with balloon engraving; picture of first aerodrome; picture of Lunardi ascent; picture of crossing the Channel by balloon; early symbolic map of England; picture of oriental aero station; picture of early kite flying; book of autographs and letters (including one from Lunardi); case (210) of aeronautical medals and plaques.

Lieut.-Colonel J. T. C. Moore-Brabazon.—No. 1 pilot's certificate; early French Aero Club pilot's certificate.

Mrs. Orme Smith.—Battersea enamel comfit box; old snuffbox (Montgolfier's balloon); two Lambeth Delft dishes; cotton handkerchief of Henson's aerial carriage; balloon medals.

Royal Aero Club.—Schneider Trophy; silver plaque of Gordon Bennett Race won by Grahame White; bronze bust of C. S. Rolls.

Air League of the British Empire.—Plaque of Holt Thomas.

Captain G. de Havilland.—British Gold Medal for Aeronautics.

Captain Urwins.—British Silver Medal for Aeronautics.

Dr. Lanchester.—The Royal Aeronautical Society's Gold Medal; The Royal Aeronautical Society's Bronze Medal; Daniel Guggenheim Gold Medal.

Mr. C. C. Walker.—The Royal Aeronautical Society's Silver Medal.

Mr. H. B. Irving.—Wakefield Gold Medal.

Professor M. Jones.—Taylor Gold Medal.

Mr. H. Sutton.—Simms Gold Medal.

Miss Littlewood.—Fifteen sheets of air stamps.

Mr. Griffith Brewer.—Balloon trophy; bust of Wilbur Wright; post card from Wilbur Wright; letter of congratulation to Mrs. Brewer from the Aero Club on being the first woman to cross the Channel by air.

Mr. Sadler.—Ivory counter box belonging to Sadler the balloonist; Sadler's compass; Sadler's medallion; balloon silk from one of Sadler's balloons; Sadler's post card; Sadler (aged 4), painting.

Mr. J. E. Hodgson.—A large number of rare aeronautical prints; aeronautical medals; balloon plates; snuff boxes; rare aeronautical books; Cayley manuscript.

Captain Lamplugh.—Early aircraft insurances.

Captain Forsyth.—Silver model of Supermarine S.6.

Sir Kenelm Cayley.—Cayley manuscript and an oil painting of Sir George Cayley.

Science Museum.—Early aeronautical tapestry.

Royal Aeronautical Society.—First air passport issued to Green, 1836; balloon post letter and cover (Paris siege); first coloured specification of Henson's aerial carriage; Glaisher's original manuscript; first Council Minutes of the Society, January 12th, 1866; first Rheims meeting programme signed by all present; Council dinner programme signed by Orville, Wilbur and Kathleen Wright; aeronautical books and manuscripts.

Mr. How.—Vernis machine box with painting of balloon, late 18th century; ivory snuff box; Montgolfier buttons; painted fan; Lambeth Delft plate.

Mr. Gautier.—Pair of balloon bowls; Lambeth Delft plates; Lambeth Delft dishes.

Messrs. Short Brothers.—First aeroplane order book.

LECTURES.

The following Lectures were read before the Society in 1936:—

January 6th.—" Sir George Cayley," by Mr. J. E. Hodgson, Hon. F.R.Ae.S.

January 20th.—" The Theory of Alloy Structures," by Professor W. L. Bragg, O.B.E., M.A., Sc.D., F.R.S.

February 3rd.—" Airscrew Development," by Dr. H. C. Watts, M.B.E., M.Inst.C.E., F.R.Ae.S.

February 17th.—" The Boundary Layer and Recent Developments," by Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S.

March 23rd.—" The Jointing of Materials by Welding," by Mr. R. H. Dobson and Mr. R. F. Taylor.

April 20th.—" New Light on the Strength of Materials Afforded by Modern Physics," by Dr. H. Gough, M.B.E., F.R.S., and Mr. W. A. Wood.

May 21st.—Twenty-fourth Wilbur Wright Memorial Lecture, " Surface Films and Lubrication," by Mr. D. R. Pye, M.A., Sc.D., M.I.Mech.E., F.R.Ae.S.

October 8th.—" Aerodynamic and Structural Features of Tapered Wings," by Dr. G. V. Lachmann, F.R.Ae.S.

October 22nd.—" The Economics of Air Line Operation," by Mr. L. T. H. Greig.

November 12th.—" The Part Played by Skin Friction in Aeronautics," by Dr. F. W. Lanchester, F.R.S., M.I.Mech.E., F.R.A.S., Hon. F.R.Ae.S.

November 19th.—" Aerodrome Design," by Mr. Nigel Norman, F.R.Ae.S.

November 26th.—Continued Discussion on " Aerodynamic and Structural Features of Tapered Wings," by Dr. G. V. Lachmann, F.R.Ae.S.

December 10th.—" Civil Flying Boats," by Mr. A. Gouge, B.Sc., F.R.Ae.S.

December 17th.—" Profile Drag," by Professor B. Melvill Jones, A.F.C., M.A., F.R.Ae.S.

BRANCH LECTURES.

Jan. 2nd.—Lecture before the Yeovil Branch, by Dr. H. J. Gough, on " The Work of the Engineering Department of the N.P.L."

Jan. 2nd.—Lecture before the Portsmouth Branch, by Mr. C. B. Carr, on " Commercial Design of Aircraft Wireless Equipment."

Jan. 7th.—Lecture before the Bristol Branch, by Mr. W. J. Richards, on " Aircraft Instruments."

Jan. 15th.—Lecture before the Hull and Leeds Branch, by Mr. E. F. Relf, on " The Compressed Air Tunnel."

Jan. 16th.—Lecture before the Coventry Branch, by Mr. P. R. Twigger, on " Development in Centrifugally Cast Piston Rings for Modern Aero Engines."

Jan. 16th.—Lecture before the Manchester Branch, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " The Stratosphere."

Jan. 16th.—Lecture before the Portsmouth Branch, by Mr. H. B. Irving, B.Sc., F.R.Ae.S., on " Wing Flaps."

Jan. 16th.—Film Display before the Yeovil Branch, " The Development of the Lathe," and three other films.

Jan. 28th.—Lecture before the Bristol Branch, by Mr. A. H. R. Fedden, F.R.Ae.S., on " Future Research on Air-Cooled Aero Engines."

Jan. 30th.—Lecture before the Portsmouth Branch, by Mr. H. L. Stevens, on " Flying Controls."

Jan. 30th.—Lecture before the Yeovil Branch, by Mr. C. H. Smith, on " Ball, Roller and Needle Bearings and their Manufacture."

Feb. 4th.—Lecture before the Gloucester and Cheltenham Branch, by Mr. C. H. Smith, on " Ball, Roller and Needle Bearings."

Feb. 12th.—Lecture before the Southampton Branch, by Mr. Dorey, on " The Modern Trend of the Liquid-Cooled Engine Installation."

Feb. 13th.—Lecture before the Portsmouth Branch, by Mr. G. H. Dowty, M.I.Ae.E., F.R.Ae.S., on " Undercarriage Developments."

Feb. 13th.—Lecture before the Yeovil Branch, by Mr. R. A. C. Brie, on " The Practical Use and Maintenance of the Autogiro."

Feb. 18th.—Lecture before the Bristol Branch, by Mr. Norman Edgar, on " Aircraft Operating."

Feb. 18th.—Lecture before the Gloucester and Cheltenham Branch, by Dr. G. P. Douglas, M.C., A.F.R.Ae.S., on " Cooling Problems."

Feb. 20th.—Lecture before the Coventry Branch, by Mr. T. E. Beacham, B.Sc., A.M.I.Mech.E., on " Variable Pitch Propellers."

Feb. 20th.—Lecture before the Manchester Branch, by Mr. R. Chadwick, A.F.R.Ae.S., on " Aeroplane Construction."

Feb. 27th.—Lecture before the Yeovil Branch, by Mr. Slee, of Shell Mex, Limited, on " Development of Fuel and Lubricating Oils."

Feb. 27th.—Lecture before the Portsmouth Branch, by Mr. S. J. Nightingale, on " Duralumin and Elektron."

March 3rd.—Lecture before the Gloucester and Cheltenham Branch, by Major C. J. Stewart, O.B.E., M.I.Mech.E., F.R.Ae.S., on " Recent Development of Instruments and Electrical Gear."

March 11th.—Lecture before the Southampton Branch, by Mr. M. Lobelle, on " American Aircraft Design."

March 13th.—Lecture before the Yeovil Branch, by Mr. Ivor McClure, D.S.O., on " Air Routes."

March 17th.—Lecture before the Gloucester and Cheltenham Branch, by Mr. G. H. Dowty, M.I.Ae.E., F.R.Ae.S., on " Retractable Undercarriages."

March 17th.—Lecture before the Bristol Branch, by Dr. G. P. Douglas, M.C., A.F.R.Ae.S., on " The 24ft. Wind Tunnel."

March 19th.—Lecture before the Manchester Branch, by Mr. T. G. Bradley, M.I.A.E., on " Modern Car Production Methods."

March 19th.—Lecture before the Coventry Branch, by Flt. Lieut. P. W. S. Bulman, F.R.Ae.S., on " Type Testing an Aircraft."

March 27th.—Lecture before the Yeovil Branch, by Mr. W. P. Savage, A.M.I.Aut.E., A.F.R.Ae.S., on " The ' Dagger ' Aero Engine."

March 31st.—Lecture before the Gloucester and Cheltenham Branch, by Mr. M. Lobelle, on " American Aircraft Design."

April 1st.—Lecture before the Southampton Branch, by Mr. S. Scott-Hall, M.Sc., A.C.G.I., D.I.C., A.F.R.Ae.S., on " Trans-Atlantic Air Services."

April 16th.—Lecture before the Coventry Branch, by Mr. J. E. Chorlton, on " Aircraft Instruments."

April 23rd.—Lecture before the Manchester Branch, by Flt. Lieut. H. F. Jenkins, on " Training for a Career in Aviation."

September 17th.—Lecture before the Coventry Branch, by Mr. H. Flower, on " Infra Red Photography."

September 24th.—Lecture before the Yeovil Branch, by Mr. J. L. Nayler, F.R.Ae.S., on " Bird Flight."

October 8th.—Lecture before the Yeovil Branch, by Mr. F. M. Thomas, A.F.R.Ae.S., on " Variable Pitch Airscrews."

October 14th.—Lecture before the Southampton Branch, by Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., on " Careers in Aeronautics."

October 15th.—Lecture before the Coventry Branch, by S. Barraclough, on " Diamet Inspected Steels."

October 22nd.—Lecture before the Yeovil Branch, by Mr. F. J. Slee, on " Oils."

October 27th.—Lecture before Bristol Branch, by Mr. D. R. Pye, F.R.Ae.S., on " Surface Films and Lubrication."

October 29th.—Lecture before the Portsmouth Branch, by Dr. H. C. H. Townend, F.R.Ae.S., on " Air Flow."

November 5th.—Lecture before the Yeovil Branch by Commander R. R. Graham, on " The Navy and the Aeroplane."

November 11th.—Lecture before the Southampton Branch by Mr. E. Brook-Williams, on " Aerial Navigation."

November 12th.—Lecture before the Portsmouth Branch on Sperry Instruments.

November 18th.—Lecture before Bristol Branch, by Mr. E. F. Relf, F.R.Ae.S., on " Aerodynamic Research and its Bearing on Future Aircraft Design."

November 19th.—Lecture before the Coventry Branch by Mr. F. Tomlinson, on " Lorenz Radio Guiding System."

November 19th.—Lecture before the Portsmouth Branch on the United Steel Companies.

November 19th.—Lecture before the Yeovil Branch by Mr. J. Lankester Parker, A.F.R.Ae.S., on " Construction of Large Aeroplanes."

December 1st.—Lecture before Bristol Branch, by Dr. Hatfield, M.I.Mech.E., M.I.A.E., A.F.R.Ae.S., on " Steels Used in the Aero Engine and Aeroplane Industries."

December 3rd.—Lecture before the Portsmouth Branch, by Major B. W. Shilson, F.R.Ae.S., on " Modern Air-Cooled Aero Motors."

December 3rd.—Lecture before the Yeovil Branch by Mr. E. W. Knott, M.I.A.E., M.S.A.E., on " Carburation and Engine Controls."

December 9th.—Lecture before the Southampton Branch by Mr. W. E. Crook, A.F.R.Ae.S., on " Wireless Applied to Aircraft."

December 15th.—Lecture before Bristol Branch, by Mr. F. R. Banks, F.R.Ae.S., on " Problems Connected with the Development of High Duty Engines and Fuels of High Anti-Knock Values."

December 17th.—Lecture before the Coventry Branch by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " The Queer Side of Flying."

December 17th.—Lecture before the Yeovil Branch, by Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., on " Noise in Aircraft."

December 31st.—Lecture before the Yeovil Branch, by Mr. W. E. W. Petter, A.F.R.Ae.S., on " Some Reflections on the Paris Aero Show."

Schools Lectures.

The Council arranged for the sixth year in succession to give lectures before Public Schools and other educational establishments. These lectures, all of which are illustrated by a large number of slides, namely, between 40 and 50 for each

lecture, are complete in themselves, so that lecturers have the minimum amount of trouble.

The President and Council wish to place on record their special thanks to all those who have so willingly given up their leisure time to help by delivering one or more of these lectures. There has been, during the past five years, a greater demand for lectures than can be acceded to, and the President and Council hope that any member who can help in this way will volunteer. They are a form of propaganda which is invaluable in the general cause of aviation, and following them there have been many inquiries for further information.

The following is a list of lectures at present available. Each lecture takes approximately one hour to deliver:—

1. The History of the Aeroplane.
2. The Aeroplane and its Uses.
3. Flying Boats and Seaplanes.
4. Training R.A.F. Pilots.
5. How an Aeroplane is Made and Flies.
6. A Trip into the Stratosphere.
7. How an Aeroplane Flies.
8. How an Aeroplane is Made.

LECTURES BEFORE PUBLIC SCHOOLS, ETC.

Jan. 30th.—Lecture before Leys School, Cambridge, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "A Trip into the Stratosphere."

Jan. 31st.—Lecture before Gunnersbury School by Mr. P. V. Hoare, D.I.C., A.F.R.Ae.S., on "How an Aeroplane Flies."

Feb. 1st.—Lecture before Sherborne School, by Mr. H. J. Penrose, F.R.Ae.S., on "A Trip into the Stratosphere."

Feb. 2nd.—Lecture before Stonyhurst College, by Mr. F. R. G. Cook, B.Sc. (Eng.), on "How an Aeroplane is Made and Flies."

Feb. 5th.—Lecture before Upton College, by Mr. E. W. Roberts, on "A Trip into the Stratosphere."

Feb. 8th.—Lecture before Herne Bay College, by Mr. E. W. Roberts, on "A Trip into the Stratosphere."

Feb. 15th.—Lecture before Eastbourne College, by Mr. S. Scott-Hall, B.Sc., D.I.C., A.F.R.Ae.S.

Feb. 15th.—Lecture before Mostyn House School, by Mr. F. R. G. Cook, B.Sc. (Eng.), on "The Imperial Air Routes."

Feb. 18th.—Lecture before Frensham Heights School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "How an Aeroplane is Made and Flies."

Feb. 18th.—Lecture before the Scottish Society, Walton, by Mr. J. T. Morton, A.F.R.Ae.S.

Feb. 21st.—Lecture before the Technical Institute, Rochester, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "Training R.A.F. Pilots."

Feb. 24th.—Lecture before Winchester School by Mr. S. Scott Hall, B.Sc., A.F.R.Ae.S., on "Some Aspects of Modern Aviation."

Feb. 25th.—Lecture before St. Paul's School, Kensington, by Mr. H. T. Winter, on "A Trip into the Stratosphere."

Feb. 25th.—Lecture at Newport, Isle of Wight, by Mr. T. H. Lloyd, on "The History of the Aeroplane."

Feb. 27th.—Lecture before Northampton Town and County School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "A Trip into the Stratosphere."

Feb. 28th.—Lecture before Willaston School, Nantwich, by Mr. F. R. G. Cook, B.Sc. (Eng.), on "A Trip into the Stratosphere."

Feb. 28th.—Lecture before Haberdashers' Aske's Hampstead School, by Mr. C. H. Jackson, B.Sc., A.C.G.I., D.I.C., on "A Trip into the Stratosphere."

Feb. 28th.—Lecture before Leighton Technical College, by Mr. S. J. Cox, B.Sc., on " The History of the Aeroplane."

March 6th.—Lecture before Clayesmore School, Iwerne Minster, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " How an Aeroplane is Made and Flies."

March 20th.—Lecture before the Barrow and District Association of Engineers, by Mr. F. R. G. Cook, B.Sc., on " Aircraft Construction."

March 21st.—Lecture before Highgate School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " A Trip into the Stratosphere."

April 2nd.—Lecture before the Wandsworth Technical Institute, by D. Hay Surgeoner, A.F.R.Ae.S., on " The Uses of the Aeroplane."

April 2nd.—Lecture before the Bishop Road Higher Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., A.M.I.Mech.E., on " The History of the Aeroplane."

April 11th.—Lecture before the Isle of Wight Natural History Society, by Mr. T. H. Lloyd, on " A Trip into the Stratosphere."

April 16th.—Lecture before the Bishop Road Higher Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., A.M.I.Mech.E., on " How an Aeroplane is Made."

April 23rd.—Lecture before the Bishop Road Higher Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., A.M.I.Mech.E., on " How an Aeroplane Flies."

April 30th.—Lecture before the Bishop Road Higher Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., A.M.I.Mech.E., on " The Aeroplane and its Uses."

April 30th.—Lecture before the League of Nations Union on " The Development of Commercial Aviation," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

May 7th.—Lecture before the Bishop Road Higher Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., A.M.I.Mech.E., on " Seaplanes and Flying Boats."

May 14th.—Lecture before the Bishop Road Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., on " Training R.A.F. Pilots."

May 21st.—Lecture before the Bishop Road Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., on " Imperial Air Routes."

May 26th.—Lecture before Denmark Hill Toc H, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " Training Pilots for the Royal Air Force."

May 28th.—Lecture before the Bishop Road Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., on " A Trip into the Stratosphere."

September 28th.—Lecture before Newark Engineering Society, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " Flying in the Stratosphere."

October 8th.—Lecture before Ampleforth College, York, by Mr. G. C. F. Ely, on " How an Aeroplane Flies."

October 16th.—Lecture before West Hartlepool Technical College, by Mr. J. Bell, A.R.Ae.S.I., on " Recent Progress in Aviation."

October 18th.—Lecture before St. Edward's School, Oxford, by Mr. A. F. Houlberg, A.M.I.Ae.E., on " The History of the Aeroplane."

October 19th.—Lecture before the King's School, Ely, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " Seaplanes and Flying Boats."

October 23rd.—Lecture at Bethnal Green, by Mr. G. O. Waters, A.R.Ae.S.I., on " The Uses of the Aeroplane."

October 23rd.—Lecture before Rutherford College, by Mr. J. Bell, A.R.Ae.S.I., on " How an Aeroplane is Made and Flies."

October 23rd.—Lecture before University College School, Hampstead, by Mr. H. T. Winter, on " How an Aeroplane is Made and Flies."

November 3rd.—Lecture before the Hayes and District Model Aero Club, by Mr. A. C. Brown, A.F.R.Ae.S., on " The History of the Aeroplane."

November 5th.—Lecture before the Royal Grammar School, Newcastle-on-Tyne by Mr. J. Bell, A.R.Ae.S.I., on " The Aeroplane and its Uses."

November 6th.—Lecture before Wakefield Grammar School by Mr. G. C. F. Ely, on " Flying Boats and Seaplanes."

November 7th.—Lecture before Brighton College by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " A Trip into the Stratosphere."

November 14th.—Lecture before Kingswood School, Bath, by Mr. H. Sutton, F.R.Ae.S., on " A Trip into the Stratosphere."

November 17th.—Lecture before Kingswood Grammar School, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., on " A Trip into the Stratosphere."

November 21st.—Lecture before Lincoln Engineering Society by Mr. J. T. Morton, A.F.R.Ae.S., on " The History of the Aeroplane."

November 21st.—Lecture before Mistley Place School, Manningtree, by Mr. H. T. Winter, on " The Aeroplane and its Uses."

November 27th.—Lecture before King's School, Rochester, by Mr. C. G. Rogers, A.M.I.Ae.E., A.F.R.Ae.S., on " A Trip into the Stratosphere."

November 30th.—Lecture before Newcastle-under-Lyme School, by Mr. A. N. Jackson, B.Sc., A.F.R.Ae.S., on " Training R.A.F. Pilots."

December 5th.—Lecture before Berkhamstead School, by Mr. M. Langley, M.I.Ae.E., A.M.I.N.A., on " A Trip into the Stratosphere."

December 14th.—Lecture before the Derby Y.M.C.A. by Mr. C. Ainsworth Davis, B.Sc., on " How an Aeroplane is Made and Flies."

STUDENTS' SECTION.

The following summarises the activities of the Students' Section for 1935-1936 Session :—

Officers and Committee for 1935-1936.

Chairman: C. H. Jackson, Esq., B.Sc., A.C.G.I., D.I.C.
Vice-Chairman: R. L. Lickley, Esq., B.Sc.
Hon. Secretary: H. Leaderman, Esq., B.A., B.Sc. (Eng.).
Committee: A. H. Yates, A. F. Walsh, B.Sc. (Eng.), R. M. Barry, B. R. Siminson.

The following meetings were held during the Session :—

1935.

October 15th.—" The Commercial Aspect of the Long-Range Flying Boat," by Mr. A. Gouge, B.Sc., F.R.Ae.S. Chairman: Major R. E. Penny, O.B.E., A.F.R.Ae.S.

November 19th.—" Tapered Wing Stalling," by Mr. P. P. Nazir, A.F.R.Ae.S. Chairman: Mr. H. E. Wimperis, C.B., C.B.E., F.R.Ae.S.

December 5th.—" The Fundamentals of Boundary Layer Theory, with Some Application to Aircraft," by Mr. H. Leaderman, B.A., B.Sc. Chairman: Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S.

1936.

January 9th.—Informal Discussion on " Stressed Skin Construction." Chairman: Mr. C. H. Jackson, B.Sc., A.C.G.I., D.I.C.

January 28th.—Colloquium on " The Technical and Scientific Aspects of the Design, Construction and Flying of Sailplanes." Chairman: Mr. S. Scott-Hall, A.C.G.I., D.I.C., M.Sc., A.F.R.Ae.S.

February 13th.—" The Design and Construction of a Light Aeroplane," by Dr. N. A. de Bruyne. Chairman: Mr. C. H. Jackson, B.Sc., A.C.G.I., D.I.C.

February 25th.—" The Mechanical Testing of Aircraft Structures and Components," by Mr. W. Tye, B.Sc. Chairman: Major C. J. Stewart, O.B.E., F.R.Ae.S.

March 5th.—" Airflow; Experiments in Flight and in the Wind Tunnel," by Mr. W. S. Coleman, B.Sc. Chairman: Mr. J. A. G. Haslam, M.C., D.F.C., A.F.R.Ae.S.

March 19th.—" The Monoplane Solution," by Mr. R. C. Abel, A.R.Ae.S.I. Chairman: Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

March 31st.—" The Test Pilot's Job," by Mr. K. Seth-Smith. Chairman: Mr. D. L. Hollis Williams, A.F.R.Ae.S.

April 28th.—" The Application of Aerodynamics to Mechanical Engineering," by Mr. J. L. B. Jones, B.Sc. Chairman: Dr. G. V. Lachmann, F.R.Ae.S.

The average attendance at these meetings was 56, at one meeting over 100 people being present.

The following visits were made:—

1935.

November 30th.—The Fairey Aviation Company, Limited, Hayes, Middlesex.

1936.

January 18th.—De Havilland Aircraft Company, Limited, Hatfield Aerodrome, Herts.

February 8th.—High Duty Alloys, Limited, Trading Estate, Slough, Bucks.

March 7th.—British Aircraft Manufacturing Company, Limited, Hanworth Aerodrome, Middlesex. General Aircraft, Limited, Hanworth Aerodrome, Middlesex.

April 18th.—The Royal Aircraft Establishment, South Farnborough, Hants.

July 4th.—The National Physical Laboratory, Teddington, Middlesex.

All visits were well attended.

There were several innovations during the Session. A printed fixture card was issued and refreshments were supplied before the meetings; notices of meetings were also inserted in the Technical Press. The Committee of the Students' Section wish to take this opportunity of thanking all representatives and others who have assisted during the past Session.

R.38 Memorial Prize.

The R.38 Memorial Prize was awarded to Captain J. Morris for his paper on " The Stressing of Rigid-Jointed Frames," printed in the Journal for June, 1936, page 420.

Awards.

At a meeting of the Council held on April 21st, 1936, the following awards were made:—

Silver Medal of the Society.

To Mr. B. N. Wallis, for his work on Geodetic Construction.

Simms Gold Medal.

To Mr. W. S. Farren, M.B.E., M.A., M.I.Ae.E., F.R.Ae.S., for his inventions of new methods of the measurement of drag and his designs of scientific apparatus for aeronautical research.

Taylor Gold Medal.

To Mr. E. F. Relf, A.R.C.Sc., F.R.Ae.S., for his paper read before the Society on " The Compressed Air Tunnel."

Sir Charles Wakefield Gold Medal.

To Mr. C. R. Fairey, M.B.E., F.R.Ae.S., for his invention and work on flaps.

Busk Memorial Prize.

To Mr. R. P. Alston, B.A., A.F.R.Ae.S., for his paper read before the Society on " Wing Flaps and Other Devices as Aids to Landing."

At a meeting of the Amulree Committee held on April 27th, 1936, the following awards were made on the recommendation of the Council of the Royal Aeronautical Society:—

British Gold Medal for Aeronautics.

Dr. Hugo Eckener for his technical achievements in lighter-than-air craft.

British Silver Medal for Aeronautics.

Mr. A. J. Rowledge, M.I.A.E., F.R.Ae.S., for his scientific achievements in the development of aircraft engines.

ELLIOTT MEMORIAL PRIZE.

The Elliott Memorial Prize was awarded to Sergeant Apprentice Willis and Leading Aircraftsman J. C. Stead.

DONATIONS.

The Council have much pleasure in announcing that Mr. C. R. Fairey, M.B.E., F.R.Ae.S., Past-President of the Society, and Mr. F. Handley Page, C.B.E., F.R.Ae.S., Vice-President of the Society, have jointly agreed to give £750 a year for seven years to the Society. The object of this generous gift is to enable the Society to carry out as fully as possible its main object, "the general advancement of aeronautical science and engineering," and to enable it to be placed on a self-supporting basis.

ACKNOWLEDGMENTS.

The Council gratefully acknowledge the following:—

Back numbers of the Journal and other Society publications from Miss L. Chitty (Fellow), Miss G. Cottrell (Companion), Mr. W. S. Farren (Fellow), Mr. R. L. Howard Flanders (Member and Associate Fellow), Mrs. J. D. Fullerton (Companion), Mr. A. E. Woodward Nutt (Associate Fellow), Mr. F. Handley Page (Fellow), Mr. E. F. Relf (Fellow), Mr. T. B. Ringwood (Associate Member), Mr. F. P. Walsh (Associate Fellow), Mrs. F. H. Wenham, and Colonel L. M. Wilson (Associate).

Slides, photographs and negatives from the National Geographic Society, Washington; Mr. J. F. Cuss (Associate Fellow), Major D. H. Kennedy (Fellow), and Mr. H. Willis (Companion).

Library books, publications and periodicals from the Director of the French Air Ministry, the British Air Ministry, Miss G. Cottrell (Companion), Mr. M. H. Volk (Fellow), Mr. H. R. Gillman (Associate Fellow), Dr. F. W. Lanchester (Hon. Fellow), Mr. H. Leaderman (Student), Lieut.-Col. M. O'Gorman (Fellow), and Mr. John Rennie.

ENDOWMENT FUND.

The Council gratefully acknowledge one guinea each from Mr. A. J. Henington (Associate Member) (for the sixth year in succession), Mr. J. W. C. Logan (Associate Member) (for the fourth year in succession), and Mr. J. D. L. Stratton (Student); and five shillings from Flight Sergeant O. S. J. Burrows (Associate).

GARDEN PARTY.

The Society held its annual Garden Party on Sunday, May 10th, 1936, at the Great West Aerodrome, near Hayes, the use of which was kindly given to the Society for the day by Mr. C. R. Fairey, M.B.E., F.R.Ae.S., a former President of the Society. The Garden Party proved to be the most successful yet held, the attendance of members and their friends exceeding by several hundreds the record attendance of 1935. Much of the success was due to the great help of

Mr. Fairey and his staff, who organised the greater part of the arrangements at the aerodrome, and to the many firms and private individuals who took part in the flying display. Special thanks are due to Flight Lieut. C. S. Staniland, who was in charge of the whole of the flying arrangements, for the most excellent organisation which enabled everything to run smoothly.

The Council wish particularly to place on record the very great debt which the Society owes to its former President, Mr. C. R. Fairey, for the loan of his magnificent aerodrome.

The following is the programme which was arranged:—

2.30—3.0 p.m.—Reception by the President, Lieut.-Colonel J. T. C. Moore-Brabazon, and Council.

Flying Programme.

3.0 p.m.—Mr. E. G. Hordern. Heston Phœnix.
3.10 p.m.—Captain E. W. Percival. Percival "Vega Gull."
3.20 p.m.—Mr. R. Seth Smith. Monospar "Ambulance."
3.25 p.m.—Mr. Macphail. Monospar S.T.25 "De Luxe."
3.30 p.m.—Captain Schofield. Monospar S.T.18 "Croydon."
3.40 p.m.—Cessna C.34.
3.55 p.m.—Mr. R. A. C. Brie. Cierva Autogiro C.30 A.
4.5 p.m.—Tea interval. Exhibition of crazy flying by Mr. Robert Kronfeld in a B.A.C. Super Drone.
4.30 p.m.—Demonstration of winch launching of sailplanes. Mr. H. Slingsby, British Falcon III (two-seater); Mr. E. J. Furlong, Cambridge II; Mr. D. Hiscox, Kirby Kite; Mr. Christopher Nicholson, Rhonsperber.
4.55 p.m.—Tea interval. Exhibition of aerobatics by Mr. J. H. Hill in an Aeronca C.3 monoplane.
5.20 p.m.—Flt. Lieut. Moir. Miles "Sparrowhawk."
5.30 p.m.—Parachute jumping arranged by Irving Air Chute Company of Great Britain, Ltd. Parachutist, Mr. F. C. Coveney.
5.40 p.m.—Flt. Lieut. Tommy Rose. Miles "Falcon Six."
5.50 p.m.—Flt. Lieut. C. H. A. Colman. Airspeed Type A.S.6 Envoy Series II.
6.0 p.m. Fire fighting display by Bell's Asbestos Company, Ltd., in conjunction with Air Ambulance demonstration by members of the County of Surrey Air Ambulance Detachment of the British Red Cross Society in the Monospar Ambulance.

The following machines, in addition to those of private owners arriving by air, were on the aerodrome, and some of which were flown during the afternoon:—

Abbott-Baynes Cantilever Pou-du-Ciel. (Carden Baynes Aircraft, Ltd., Heston.)
Blackburn B2 Trainer. (The Blackburn Aeroplane Co., Ltd., Brough.) (Shown by Flying Training, Ltd., Feltham.)
B.A.C. Super Drone. (B.A.C., Ltd., Feltham.)
B.A. Eagle. (British Aircraft Manufacturing Co., Ltd., Feltham.)
B.A. Swallow. (British Aircraft Manufacturing Co., Ltd., Feltham.)
Cessna C.34. (The Cessna Aircraft Co., Kansas, U.S.A.) (Shown by Surrey Flying Services, Ltd., Croydon.)
Cierva Autogiro C.30 A. (The Cierva Autogiro Co., Ltd., Hanworth.)
De Havilland Hornet Moth. (De Havilland Aircraft Co., Ltd., Hatfield.)
De Havilland Dragonfly. (De Havilland Aircraft Co., Ltd., Hatfield.)
Fairchild 24. (Fairchild Aircraft Corporation, Maryland, U.S.A.) (Shown by D. Campbell Shaw, Esq., private owner.)
Fairey Battle. (The Fairey Aviation Co., Ltd., Hayes.)
Fairey Swordfish. (The Fairey Aviation Co., Ltd., Hayes.)

Monospar de Luxe. (General Aircraft, Ltd., Feltham.)
Monospar Croydon S.T.18. (General Aircraft, Ltd., Feltham.)
Monospar Ambulance. (General Aircraft, Ltd., Feltham.)
Heston Phœnix. (Heston Aircraft, Ltd., Heston.)
Aeronca C.3. (Aeronautical Corp. of America, Cincinatti, U.S.A.) (Shown by Light Aircraft Co., Ltd., Park Lane, W.1.)
Percival Vega Gull. (The Percival Aircraft Co., Ltd., Grosvenor Place, W.1.)
P.A.C. Pou. (Puttnam Aircraft Co., Ltd., Hornsey, London.)
Miles Falcon Six. (Phillips and Powis Aircraft, Ltd., Reading.)
Miles Sparrowhawk. (Phillips and Powis Aircraft, Ltd., Reading.)
Miles " Whitney Straight " Monoplane.
Avro Staggered Cadet. (A. V. Roe and Co., Ltd., Newton Heath, Manchester.) (Shown by Airwork, Ltd., Heston.)
Saro Cloud. (Saunders-Roe, Ltd., Cowes, I.O.W.)
Short Scion. (Short Bros., Ltd., Rochester,) (Shown by Airwork, Ltd., Heston.)
Stinson Junior. (Stinson Aircraft Co., U.S.A.) (Shown by Airwork, Ltd., Heston.)
De Havilland Express Air Liner (DeH.86a). Used on the Scandinavian Services of British Continental Airways.
De Havilland Dragon Rapide (DeH.89). Used on the Cross-Channel Services of British Continental Airways.
Airspeed Envoy Series II (Type A.S.6). (Airspeed (1934), Ltd., Portsmouth.)
Airspeed Courier. (Airspeed (1934), Ltd., Portsmouth.)
De Havilland Leopard Moth. (De Havilland Aircraft Co., Ltd., Hatfield.) (Shown by C. G. Vokes, Ltd., Putney.)
Rolls Royce Heinkel. (Ernst Heinkel Flugzeugwerke G.m.b.H., Germany.) (Shown by Rolls Royce, Limited, Derby.)
De Havilland 86. Used by Imperial Airways.
Carden-Baynes Auxiliary Sailplane. (Carden-Baynes Aircraft, Ltd., Heston.)
British Falcon III. (Exhibited by London Gliding Club, Dunstable. Designed and constructed by Slingsby, Russell and Brown, Ltd., Yorks.)
Cambridge II. (Exhibited by Capt. R. L. Rattray and E. J. Furlong, Esq. Designed and constructed by Dart Aircraft, Ltd., Dunstable.)
Kirby Kite. (Exhibited by D. Hiscox, Esq. Designed and constructed by Slingsby, Russell and Brown, Ltd., Yorks.)
Rhonsperber. (Exhibited by the joint owners, R. P. Cooper, Esq., Christopher Nicholson, Esq., and J. P. Dewsbury, Esq.)
Maurice Farman (1913), Type F.40. Fuselage only. (Exhibited by the International Horseless Carriage Corporation, Weybridge.)

During the afternoon there was a running commentary on the flying demonstrations by Mr. William Courtenay, A.R.Ae.S.I.

The car parking and aeroplane parking were carried out by the Automobile Association, and the Council wish to record their thanks for the great help which was given.

During the afternoon the Central Band of H.M. Royal Air Force (by permission of the Air Council) under the personal direction of Flight Lieutenant R. P. O'Donnell, M.V.O. (Director of Music, Royal Air Force) played a series of selections.

The following is a list of Members and Guests attending the Royal Aeronautical Society's Garden Party on Sunday, May 10th, 1936, at the Great West Aerodrome.

R. C. Abel, Esq., A.R.Ae.S.I.; Miss F. Abel; C. F. Abell, Esq., O.B.E., A.F.R.Ae.S.; Mrs. C. F. Abell; Major G. H. Abell, O.B.E., A.M.I.Aut.E., A.F.R.Ae.S.; Mrs. G. H. Abell; Captain P. D. Acland; Mr. Adachi; D. R. Adams, Esq., A.F.R.Ae.S.; Mrs. D. R. Adams; Miss M. Adams; Miss G. Adams; Mr. H. Adams; H. F. Adams, Esq.; Mrs. H. F. Adams; N. Keith Adams, Esq.; Mrs. M. Adams; Vyvyan Adams, Esq., M.P.; E. N. Adlington, Esq.; J. Aherne-

Heron, Esq.; Capitaine de Corvette Albertas (French Air Attaché); Madame Albertas; R. M. Alcock, Esq., A.F.R.Ae.S.; Patrick Alexander, Esq., Hon. F.R.Ae.S.; Dr. P. C. Alexander; Mrs. P. C. Alexander; W. Algie, Esq., D.S.O.; Mrs. Algie; P. Allander, Esq.; Mr. and Mrs. Allen; D. G. Allison, Esq.; C. G. M. Alington; Miss Dorothy Allmand; Monsieur Amboldt; Lord Amulree, P.C., G.B.E. K.C.; H. Andreae, Esq.; Mrs. H. Andreae; Monsieur Angelov; A. H. Ansell, Esq.; Mrs. A. H. Ansell; L. D. Anscombe, Esq.; Miss Anstill; Captain Natal Arnaud (Acting Naval Attaché, Brazilian Embassy); Madame Natal Arnaud; Major D. Carmelo de las Morenas Alcala (Spanish Air Attaché); R. H. L. Arnold, Esq.; Mrs. Arnold; Miss J. Arnold; Miss D. Arnold; E. J. Arnsby, Esq.; W. L. Atkins, Esq.; Mrs. W. L. Atkins; J. R. Ashwell-Cooke, Esq.; Automobile Engineer Representative.

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H. M. Yeatman, Esq., M.A., A.F.R.Ae.S.; Miss P. Young; Miss W. D. Young; Captain F. T. Young; R. T. Youngman, Esq., A.F.R.Ae.S.; Mr. Yoxall ("Flight").

J. F. L. Zollner, Esq.

OBITUARIES.

The Council greatly regret to record the deaths of the following members of the Society during the year:—

SIR RICHARD TETLEY GLAZEBROOK, F.R.S., *Honorary Fellow*, 1854-1936.

Richard Tetley Glazebrook was born in Liverpool on September 18th, 1854. He graduated as Fifth Wrangler in 1876 and was elected a Fellow of Trinity College, serving from 1881-1896 as lecturer and assistant tutor. In 1880 he was appointed a demonstrator at the Cavendish Laboratory by Lord Rayleigh and later became assistant director. He was largely concerned there with teaching practical physics with Sir Napier Shaw, their work forming the foundation of the Textbook of Practical Physics. Glazebrook published a number of papers on the theory of light and the determination of fundamental electrical units, and in 1882 was made a Fellow of the Royal Society, afterwards, in 1909, receiving the Hughes Medal and in 1931 the Royal Medal.

In 1898 Glazebrook became Principal of University College, Liverpool, and the following year was appointed the first director of the National Physical Laboratory, from which post he retired in 1919. The work which Glazebrook did at the N.P.L. was of incalculable value. It comprised only two departments at its opening, physics and engineering, with a total staff of only 26. When he retired the staff had increased twentyfold and new departments had been formed, including that of aeronautics.

Glazebrook's range of activities covered almost every branch of science. He was for many years the secretary of the Electrical Standards Committee of the British Association, was President of the Institution of Electrical Engineers (1906-7), of the Physical Society (1903-5), and of the Optical Society (1903-4, 1911-12). He was chairman of the Advisory Committee for Aeronautics from its formation in 1909, and also until 1933 of the Aeronautical Research Committee which succeeded it in 1920. From 1920-23 he was Zaharoff Professor of Aviation and Director of the Aeronautics Department in the Imperial College of Technology. In 1933 he was awarded the Gold Medal of the Royal Aeronautical Society, a member of which he had been for many years. The author of many papers and textbooks, he was the Editor of the Dictionary of Applied Physics. He was knighted in 1917.

By the death of Sir Richard Glazebrook aviation lost one of its leading figures who, by his work at the N.P.L. and as chairman of the A.R.C., did much to make the science of aeronautics what it is to-day.

JOHN LORD, *Fellow*, 1936.

By the sudden death of John Lord on January 25th aviation lost one of its best known and best beloved figures. He saw the growth of aviation from the beginning, joining A. V. Roe when the latter began making aeroplanes in 1909-10. He did not have an opportunity to show his real worth and organising ability until the last two years of the Great War. From that time he rose rapidly until he became known to everyone in the aircraft industry as a man of the highest ability and integrity. Much of the outstanding success of A. V. Roe and Co., indeed, can be traced to his managership.

When the firm was absorbed into the Siddeley organisation John Lord and A. V. Roe retired, and with S. Saunders, the motor boat pioneer, founded Saunders-Roe, Ltd., which with its series of amphibians rapidly became one of the leading firms in the country.

John Lord joined the Society in 1912 and was elected a Fellow in 1928. He was for many years a member of the Finance Committee and did much to help the Society in its many activities. He was a man who made no enemies but innumerable friends, and by his death aviation lost not only one of its pioneers, but one who will be long remembered for his kindliness, generosity and ability.

Sir Joseph Petavel, F.R.S., *Fellow*, 1873-1936.

Joseph Ernest Petavel was born on August 14th, 1873, and educated at University College, London. In 1900 he went to Owen's College, Manchester, as John Harding Research Fellow. In 1908 he was appointed Professor of Engineering and Director of the Whitworth Laboratories of Manchester University, where he worked on the attainment of very high pressures. The following year he was appointed one of the original members of the Advisory Committee for Aeronautics, on which he served after it became the Aeronautical Research Committee, until his death. In 1911 he was appointed a member of the General Board of the National Physical Laboratory and in 1919 he became the director. Knighted in 1920, Sir Joseph Petavel served on many important committees and councils and was a Past-President of the Engineering Section of the British Association.

Sir Joseph Petavel was essentially an engineer, though most of his work, as an administrator, prevented him from carrying out fully many of his own ideas. Elected to the Society in 1910, his death was a great personal loss to the large circle of friends he had made in aviation.

John Laurence Hodgson, *Associate Fellow*, *d.* August, 1936.

John L. Hodgson was an engineer of great ability and originality. He had a very wide range of interests and took an active part in the discussions of the societies to which he belonged. He made the subject of waste particularly his own and showed how, by co-ordinated effort and the proper use of machinery, the working hours of the world could be at least halved. He took a keen interest in all aeronautical questions and was one of the pioneers on testing model airscrews. He was elected an Associate Fellow of the Society in 1912.

Robert Alexander Tarleton, *Member and Associate Fellow*, *d.* November, 1936.

R. A. Tarleton was killed in an aeroplane accident near Jodhpur, India, on November 16th, 1936, while on a tour of inspection for the Jodhpur Railway, of which he was the locomotive and carriage superintendent.

Tarleton was a member of the Institution of Aeronautical Engineers before its amalgamation with the Royal Aeronautical Society and also an Associate Fellow of the Society. He served in the Royal Air Force during the war, and though a locomotive engineer, whose duties kept him in India, he continued to keep up his interest in aviation and took every opportunity to fly.

George Geach Parnall, *Companion*, *d.* June, 1936.

George Parnall was a member of the firm of George Parnall and Sons, shopfitters, which, during the Great War, turned their activities towards building aeroplanes. The interest he then acquired in aircraft was one George Parnall never lost, and when, following the war, his firm sold their business, he decided to enter the aircraft industry. A pioneer of many new and experimental designs, he spared no money to further any project which held out any hope of success. Among the most interesting of the machines produced by George Parnall and Co. was the Parnall Parasol Research monoplane for the purpose of carrying out full-scale research.

Squadron Leader Rollo A. de Haga Haig, *Associate Fellow*, 1896-1936.

Squadron Leader R. A. de Haga Haig was drowned in a yachting accident near Plymouth on November 10th, while trying to adjust the foresail in a storm.

Born at Newcastle-on-Tyne in 1896, de Haga Haig joined the Royal Flying Corps from the Infantry in 1916 and was quickly recognised as being a pilot of

far above the average ability. Following the war he became a test pilot at the Royal Aircraft Establishment at Farnborough, and in 1925 carried out the brilliantly successful experiment of flying from the airship R.33 and hooking on to it again. Two years previously he had given, at the R.A.F. Pageant, one of the most brilliant displays of aerobatics and fighting manœuvres ever seen at the pageant.

In 1926 he became the test pilot for William Beardmore and Co. and there worked on the monospar system of construction with Mr. H. J. Stieger and afterwards was largely concerned in developing this method of construction.

More recently he was concerned with the radiaura device, which holds out great possibilities for increasing the safety of flying.

De Haga Haig became an Associate Fellow of the Society in 1923. A most brilliant pilot, a mechanical genius, he was one of the best liked personalities in aviation and his early death leaves a gap hard to fill.

MISS GLADYS COTTRELL, *Companion*, *d.* July, 1936.

Miss Gladys Cottrell joined the Society in 1929 as a Companion, and though not technically trained, showed a very keen interest in aviation and in the training of women engineers.

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No. 84, Ricerche Sperimentali Sulle Vibrazioni Flesso-Torsionali di un Modello di Ala Con Rigidezze Variabili, P. Cicala.

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No. 86, Il Sistema Elastico Pneumatico-Ammortizzatore all'atterraggi degli Aeroplani, Ing. Ezio Lorenzelli.

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TECHNICAL PUBLICATIONS OF THE INTERNATIONAL TIN RESEARCH AND DEVELOPMENT COUNCIL

No. 22, Improvement in the Quality of Tinplate by Superimposed Electro-deposition of Tin, A. W. Rothersall and W. N. Bradshaw.

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No. 28, The Electro-deposition of Bronze, Using Bi-Metallic Anodes, D. J. Macnaughtan and C. Bechard.

Series A

No. 31, The Constitution of the Tin-Rich-Antimony—Tin Alloys, by Prof. D. Hanson and W. T. Pell-Walpole.

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No. 45, The Retarding Effect of Stannous Salts on the Oxidation of Olein and Oils, Dr. Ing. S. H. Bertram.

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No. 133, February, 1936, Experimentelle Untersuchungen uber Augen-Blendung; No. 134, February, 1936, On the Directional Properties of Airscrew Sound, J. Obata, Y. Yosida and U. Yosida.

No. 135, February, 1936, JS—Diagrams for Air, Seüchi Awano.

No. 136, February, 1936, The Nature of the Torsion-Aileron Flutter of a Wing as Revealed by Analytical Experiments, Katsutada Sezawa and Kei Kuho.

No. 137, March, 1936, Boundary Interference of Partially Closed Wind Tunnels, Kazno Kondo.

No. 138, April, 1936, Properties of Aluminium Sheet, Sadao Horiguchi.

No. 139, May, 1936, Experimentelle Untersuchungen über Licht-Schleier, by Yenziro Awadi, Tuyosi Ogisaka, and Siniti Kawasima.

No. 140, June, 1936, The Nature of the Deflection-Aileron Flutter of a Wing as Revealed through its Vibrational Frequencies, Katsutada Sezawa and Satosi Kubo.

No. 141, July, On the Relation between the Performance and the Loudness of Sound of an Airscrew, J. Obata, S. Kawada, Y. Yosida and U. Yosida.

No. 142, August, Sputtered Palladium Films, Part I, Cracks and Crumples Caused by Organic Contaminations, S. Tanaka.

No. 143, August, Buckling of a Rectangular Plate with Four Clamped Edges Re-examined with an Improved Theory, K. Sezawa and W. Watanabe.

No. 144, September, 1936, Entropy Diagrams for Combustion Gases of Gas Oil, K. Tanaka, S. Awano, T. Ohino, M. Kobayashi.

INSTITUTE OF PHYSICAL & CHEMICAL RESEARCH, JAPAN

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The Climate of the Gulf of St. Lawrence and Surrounding Regions in Canada and Newfoundland, as it Affects Aviation, W. E. Knowles Middleton.

Prevision du Temps par L'Analyse des Cartes Meteorologiques, by Jacques Van Meighem.

REVIEWS.

War Over England.

By Air Commodore L. E. O. Charlton, C.B., C.M.G., D.S.O. Published by Longmans, Green and Co. Price 12/6.

It is difficult to decide how to class this book. It is not a novel, for the greater part of it is historical. It is not really a history, for the historical part is merely an introduction to a prophetic account of the next war, by a prophet who is obviously and naturally biased in favour of his own particular weapon.

The earlier chapters contain a short but excellent account of the German air attacks on this country during the last European war. These are followed by others containing a more detailed account of the effects of individual bombs in the London area, including the case of the bomb which fell on a Poplar infant school, killing 16 and injuring 30 children. The horror which this event occasioned will be widely remembered. It is curious to note that more than this number of children are killed or mangled by motor vehicles during every week in the year and that horror is not aroused. Is the difference in the public attitude due to the fact that in one case the casualties occurred instantaneously in one spot, while in the other they are distributed over the whole country?

After this we come to the real kernel of the book, the prophetic account of the next war. This starts, unheralded by an ultimatum or otherwise, by a German air attack on the Air Pageant at Hendon, in which high explosive, gas and incendiary bombs are used, with the result that the Royal Air Force is crippled. Apart from the fact that the Germans seem to have arranged for the precise type of weather which would be best suited to such an enterprise, one suspects that Air Commodore Charlton is not being quite fair to his own Service. Is the Air Force really quite so helpless against such an attack as he describes? Is it really true that there are no immediately available stores of bombs and ammunition which would enable our machines to be armed in time to retaliate? Would not massed bombing attacks on Germany follow immediately, and would not the certainty of these counter attacks and the casualties which would be inflicted on the German raiders prove that such enterprises do not pay?

The last war might have started by the Germans making a surprise submarine attack on the British fleet. Had they done so the enterprise might have succeeded in crippling the Navy, and, had this happened, the war would have been won almost before it began. This did not happen, and the reason probably is that such attempts are too risky, they might succeed or they might not, and, if the latter occurs, the loss to the attacker might be decisive. A nation deliberately causing a war does so because it is certain of winning, an attitude which is not consistent with risking everything on a single throw of the dice.

After this event further raids take place, in one of which the underground railways of London are brought to a standstill by the bombing of a power station. The passengers stop in the carriages until they are suffocated instead of walking through the tunnel and climbing to the surface by means of the station staircases. However, eventually England capitulates, but, after a recovery period, regains its old position in the world. Finally, in conjunction with the United States, she becomes the dictator of Europe, and the book ends with the resurrection of the League of Nations.

But the Italian air attack on the British fleet in Alexandria harbour must not pass without comment, especially as the author adopts the extreme Air Force point of view in this matter, for the fleet is, apparently, immediately destroyed.

It is well known that a torpedo exploding close to a battleship will not sink it, why then should this happen as the result of a bomb bursting some distance away? Again, modern heavy ships are well protected against plunging fire from large armour piercing projectiles which are known to do much more damage than high explosive shell. This latter is similar in its effects to the aerial bomb, and it would seem that the author attributes some special lethal quality to explosive dropped from an aeroplane which does not obtain when the same quantity of the same explosive is contained in a shell fired from a gun.

The book is well worth reading, for its historical portion especially. The part dealing with the future war panders somewhat to sensationalism, but if it encourages lay readers to appreciate the importance of a strong air force, it will not have been written in vain.

AIRCRAFT DESIGN.

By Edward P. Warner, M.Sc., F.I.Ae.S., F.R.Ae.S. Published by McGraw-Hill Publishing Co., Ltd. Price 36/-.

This is the second edition of a book written by Mr. Warner some nine years ago. So great has been the advance in aerodynamical knowledge since then that it has been necessary to re-write the whole book, so that to all intents and purposes it is a new textbook on the subject.

It should be stated that the subject treated here is performance, and that another volume will follow on stability and control. Performance naturally includes much aerodynamical matter.

Primarily, it is written for engineers and designers. Mr. Warner recognises, rightly, that much of the mathematics of theoretical aerodynamics is beyond the knowledge of technicians. It is probable that this will always be the case, for a first-class mathematical brain is not normally capable of dealing with practical design.

This matter may in future be a serious dilemma, as the mathematics of the subject becomes even more complicated. It is obviously most undesirable that a designer should use formulæ the derivation and theory of which he does not understand, while it may be impossible for him to acquire the necessary knowledge for his full enlightenment. This book may be considered as an attempt, and a very successful attempt, to solve this problem as it exists to-day.

While Mr. Warner relies very largely on verbal explanation, he does not disdain the use of mathematics where its use is necessary, but explanation is the keynote of the book. He has a style which is clear and lucid, and it is difficult to imagine that matters of this kind can be made any clearer. I do not believe that any experienced designer could read this book carefully without finding his knowledge clarified on matters he already knew, and without adding to his stock of information.

While Mr. Warner explains, he takes care that those who want and can appreciate full information know exactly where to look for it. All references to bibliographical matters are in footnotes to the papers and are consequently in the best possible position for easy reference. Most of the publications referred to are by the Aeronautical Research Committee, the National Advisory Committee for Aeronautics, and the Journal of the Royal Aeronautical Society, but there are many of much interest from other sources. These footnotes are a most important feature of the book.

It remains to be said that the book contains a discussion on almost all matters which concern the performance of an aeroplane, including engine matters, and perhaps the sole criticism which can be made is that this latter subject is worthy of fuller treatment. Everything else is adequately dealt with, and there is much useful data on such up-to-date matters as variable pitch propellers.

This is, I believe, the best textbook of its type which has appeared in any language, and it can be very thoroughly recommended to all those concerned.

RIGGING AND AIRFRAMES.

By J. Campbell Corlett, A.R.Ae.S.I. Published by Sir Isaac Pitman and Sons, Ltd. Price 5/-.

This book is an attempt to present a general outline of the principles of aircraft construction and maintenance in a simple form, and is intended to fill the gap between technical and non-technical books.

As such, it is proper that it should start with a glossary so that technical terms may be properly defined. But the author has taken the definitions given in the B.S.I. standard glossary and added to them something of his own, with the result that they are often wrong. The definition of an aerofoil has nothing whatever to do with the fact that it is generally used at an angle of incidence, and a symmetrical aerofoil is never used for a wing surface of ordinary monoplanes. A normal cambered section is more suitable. The definition of eddy resistance as a pressure on all parts of an aeroplane seen in front elevation plus a so-called sucking effect by certain eddies, suggests lack of knowledge of the subject. Why not give the complete official definition, and, separately, any explanation which appears to be necessary?

The rest of this book consists of chapters on tools, types of construction, materials, assembling and trueing, and on flying and taxying faults, from the point of view of those who have to correct them. These chapters are full of useful information and the book will be worth studying by those who desire to know something about these matters. It will fill a useful place as an introduction to works of a more advanced nature. But the glossary should be revised at the first opportunity.

THE COLLECTED PAPERS OF RHYS JENKINS, M.I.Mech.E.

Newcomen Society, 1936.

The Newcomen Society was founded in 1920 for the study of the history of engineering and technology. In the brief sixteen years since its foundation it has taken an important place. It has published its *Transactions*, and in 1928 began that series of important *Extra Publications* dealing with links in the history of engineering and technology from Tudor times. The Collected Papers of Rhys Jenkins is the fourth of such *Extra Publications*, the third of which was of outstanding interest to those in aviation as it comprised the Miscellaneous Note-Book of Sir George Cayley.

From 1884 to 1920 Rhys Jenkins was on the Examining Staff of the Patent Office, and there he began the collection of notes, transcripts and extracts from printed and MS. sources relating to industrial sources which is one of the most remarkable in the country.

The present volume opens with a description of the patent obtained by John Payne, of Canterbury, in 1573 for the invention of "certayne mylnes for grindynge of Corne." There are papers on the Vauxhall Ordnance Factory of King Charles I and the Marquis of Worcester; and, astonishingly, Railways in the Sixteenth Century; the Note-book of Roger North, here published for the first time; the work of Savery, Newcomen and others on the steam engine; that of Trevithick; chapters on hydraulic and sanitary engineering of the sixteenth century, and paper making in England in the fifteenth century.

As a record for unusual and often unexpected sources, the volume is accurate, absorbingly interesting, and widely varied in its scope. It is beautifully produced, and is one which should be on the shelves of all interested in the history of engineering.

THEORY OF ELASTIC STABILITY.

S. Timoshenko. McGraw-Hill Publishing Company, Ltd., 1936. Price 36/-.

Aircraft engineering has been responsible for an immense advance both in the application of old and in the development of new methods of calculating the failing

loads of engineering structures generally. To aircraft engineering, indeed, many other forms of engineering are now looking, for the aircraft engineer, by the very nature of the fundamental problems which face him, has been compelled, if not to make the best use of the materials at his disposal, at least to make a very serious attempt to do so. And in the process he has been led to the development of new materials, new methods of using them, and new methods of construction which have led to the steady building up of a new technique.

The failure of the older forms of engineering structures by elastic instability was comparatively unknown in practice, and such problems as were solved were looked upon as pretty exercises for the mathematician. Two hundred years ago the great Euler himself dealt with the lateral buckling of struts, a problem looked upon then as purely academic.

One of the chief difficulties facing the aircraft engineer at present is the mass of material which is only available in scattered papers in many languages, papers which not only want co-ordinating but which want their contents put in a form more easily applicable by the engineer.

Professor Timoshenko, who is the Professor of Engineering Mechanics at the University of Michigan, in The Theory of Elastic Stability, has not only collected together the great amount of scattered material now available, but he has produced it in such a form that his book is a first-class publishing event. Professor Timoshenko's own original work in the field with which he treats is internationally known and extends over thirty years. Theory of Elastic Stability is an outstanding contribution to the subject, one which can only be assessed at its real importance in a few years' time. But in its pages the aeronautical engineer will find material which will throw a bright light on many of his darkest problems.

The book begins with a consideration of the bending of prismatic bars under the simultaneous action of axial loads, problems familiar to the aeronautical engineer. The chapter contains important notes on continuous beams rigidly connected to columns, continuous beams on elastic supports, and combined bending and compression beyond proportionate limits.

Chapter II deals with struts and is a treatise in itself. It is interesting to note how early some of the problems which are every-day aeronautical ones were considered and placed in the limbo of forgotten things until practical considerations demanded their further investigation. In aircraft, where weight is of major importance, struts of varying cross section are often used, and the differential equation of the deflection curve for such struts was derived by Euler, and later by Lagrange. Of importance to the aircraft engineer is the buckling of built-up struts and the effect of shearing forces on the critical load of such struts. Attention may be drawn, too, in this chapter, to the section on the Stability of a System of Elastic Bars.

Chapter III deals with Experiment and Design Formulas and discusses the various empirical formulas used. The following chapter deals with the important problem of the curved strut. Chapters V, VI, VII and VIII will more than repay close study by the aeronautical engineer, for they are concerned with problems which are of great importance in aircraft structures, the lateral buckling of beams, the buckling of thin plates, and the buckling of shells. On these problems the author has carried out many investigations. The stressed skin, the monocoque fuselage, and the thin-webbed deep spar sections are all problems which come within the scope of these chapters, and there are many references to the work of investigators in this field, some of them surprisingly early. The first experiments with buckling of thin webs transmitting shearing and bending stresses were made by William Fairbairn, for example, in connection with the construction of the famous Britannia and Conway tubular bridges and published by him in 1849, and other experiments in connection with the bridges were published in the following year by Edwin Clark. Houbotte, the Belgian engineer, was also one of the early experimenters on plate girders, publishing his results in 1856. A. E. H. Love, in the fourth edition of his Elasticity developed the

general theory of the bending of thin shells. These chapters, indeed, are a revelation of the work which has been done on the plates and shells under various forms of loading work which has been sadly neglected until recently. The progress which is now being made, much of it due to Professor Timoshenko himself, is a tribute to the control of difficult mathematical processes by many investigators.

It is invidious, however, to pick out any portion of this remarkable book and comment on it in detail. Surveyed as a whole, Professor Timoshenko's work is an outstanding contribution to this side of engineering, and it is only using a cliché to say the book can be thoroughly recommended. Something far more than that should be said of it, something which the paucity of the English language in some respects makes it difficult to say. It is a book which *must* be bought and read and re-read by anyone who is concerned with the increasing number of problems which have to be faced daily with the growth of the newer forms of metal construction and the limitations of weight which demand of the aeronautical engineer the utmost skill and the constant use of greater and greater refinements in methods of estimating the strength of his structures. To such the Theory of Elastic Stability is indispensable and vital.

SNOW STRUCTURES AND SKI FIELDS.

By G. Seligman. Published by Macmillan. Price 25/-.

Switzerland is a country where a considerable section of the population depend for their living on the sports, which depend on the co-existence of snow and hills—sports which may, and often do, become extremely dangerous under certain conditions of snow and weather.

Mr. Seligman has the advantage of considerable practical experience in this matter, his scientific knowledge has enabled him to devise and carry out many interesting experiments, and the combination has enabled him to produce a book which should interest all who are inclined to winter sports and which contains information which may save life.

It will be a surprise to those who read this book to learn in how many forms solid water may exist. It is not easy to add them up, but on a rough estimate about forty different forms are described in this book, many with characteristic crystalline shapes. We are told that the snowflake itself alters rapidly after falling, and that the subsequent history of the snow depends on atmospheric conditions, each of which produces its own peculiarity in the snow layer. The question of avalanches is dealt with in detail, and the conditions which lead to instability of snow on a sloping hillside are discussed. It will be news to many who do not know Switzerland that the air blast caused by a large avalanche can destroy trees at a considerable distance, and also bring down other avalanches.

The book has no direct concern with aviation, but it is well worth reading as a work of general interest. The illustrations are excellent in technique and are very well chosen.

HIGH FAILURE.

By John Grierson. Published by William Hodge and Co., Ltd. Price 12/6.

This book is a description of the author's flights in small seaplanes over the so-called Arctic Air Route, and it is a very interesting record of the adventures and dangers of flights of this nature.

Books of this nature form an important part of the history of aeronautics. They show the troubles that beset those who first explored the world in aeroplanes and the pluck and resource that these flights produced. It is possible that at some future time a traveller in a luxurious air liner may be reading this book while passing over the author's route. He would be able to appreciate it; to see the conditions of almost perpetual fog, the desolation of frozen and uninhabited land, and to imagine the feelings of the lone pilot.

But the time for this route has not arrived, for there are several serious disadvantages. Fog is not of very much importance to a modern air liner, provided that the pilot can see to land. If he cannot, there is no apparatus in existence which can lead him safely to the surface of the land or water, though in the future this problem will be solved.

But, even then, there is another difficulty. However easy it may be in the future to alight blind on the sea, it will still be impossible to do so if the water is liberally sprinkled with ice floes, any one of which might punch such a hole through the bottom of the boat as would lead to its total loss. There is no solution for this difficulty that can be foreseen, and it is not easy to see how it can be solved, except possibly by using aeroplanes and aerodromes and abandoning water alighting altogether.

The book itself is well written and well illustrated, and it is an excellent example of its type. Mr. Grierson can be congratulated on his penmanship as well as on his airmanship.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

JANUARY, 1936

New Year Greetings

The President and Council wish to convey to all Members of the Society, at home and overseas, the hope that 1936 will prove for them all one of increasing happiness and prosperity.

The Society's Seventieth Birthday

On Sunday, January 12th, 1936, the Society will celebrate its 70th birthday. It is the oldest aeronautical institution in the world with an unbroken record.

Founded on January 12th, 1866, as the Aeronautical Society of Great Britain, it has watched the growth of aviation from the days when flying, as it is known to-day, was but a dream of the distant future. Before it has been read no fewer than 600 papers on every aspect of aviation from ballooning to gliding flight, from the flight of birds to the construction and flight of great flying boats; in the pages of its Journal has appeared papers by nearly every leading authority; in its roll of members has appeared the names of all those who have brought aviation to the stage when it is on the threshold of becoming the greatest form of transport in the world. Among its members may be mentioned James Glaisher, the meteorologist and balloonist; Horatio Phillips, of " Phillips entry " fame; F. H. Wenham, whose paper, read on June 27th, 1866, on " Aerial Locomotion " laid down the principles of mechanical flight and became a classic; Sir Hiram Maxim; P. S. Pilcher; Lord Rayleigh, Lawrence Hargrave; and Professor G. H. Bryan. Its present list of members bears eloquent testimony to the high prestige of the Society and it would be invidious to pick out more than one name, that of one of its former Presidents, Major B. F. S. Baden Powell, who joined the Society in 1879 and so has been a member for the astonishing period of 57 years.

Its Gold Medal, the highest honour it can confer, has been awarded to Wilbur and Orville Wright, Octave Chanute, Professor Bryan, E. T. Busk, Professor Lanchester, Professor L. Prandtl and Sir Richard Glazebrook, all of whom have been or are members of the Society.

The full record of the Society's work is in the pages of the Society's Journal, in the Annual Reports of the Council. To give that history only briefly would take up too much space here. Here can only be placed on record the remarkable fact that on January 12th, 1866, was founded a society devoted to aviation and that that Society is now the premier aeronautical society of the world.

New Year Honours

Viscount.

Marshal of the Royal Air Force Hugh Montague Baron Trenchard, G.C.B., G.C.V.O., D.S.O., D.C.L., LL.D. (Honorary Fellow).

Knight.

Lieut.-Colonel Francis Claude Shelmerdine, C.I.E., O.B.E. (Fellow).

C.B. (Military Division).

Air Vice-Marshal Henry Meyrick Cave-Browne-Cave, D.S.O., D.F.C. (Fellow).

Air Commodore Napier John Gill, C.B.E., M.C. (Associate Fellow).

O.B.E.

Herbert Lawrence Stevens, Esq. (Fellow).

List of Members

With the January issue of the *Journal* is circulated the List of Members for 1936. In future the List of Members will be published with the January issue of the *Journal*.

Imperial Airways Exhibition

Imperial Airways, who are holding an Exhibition of their organisation at the Science Museum, Exhibition Road, South Kensington, are giving a special private view to members of the Royal Aeronautical Society and members of the Air League of the British Empire at 8.30 p.m., on January 17th, 1936. Light refreshments will be served. Admission will be by ticket only and applications for tickets should be made to Imperial Airways, Airways House, Charles Street, S.W.1. It is hoped that as many members of the Society as can will accept this invitation.

Meeting of Council

A Meeting of the Council was held in the Offices of the Society on Tuesday, December 10th, 1935, when the following members were present:—

Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair; Captain P. D. Acland, Major G. P. Bulman, Mr. R. S. Capon, Mr. H. Roxbee Cox, Mr. E. C. Gordon England, Mr. S. Scott-Hall, Professor F. T. Hill, Professor G. T. R. Hill, Major D. H. Kennedy (Honorary Treasurer), Captain A. G. Lamplugh, Mr. W. O. Manning, Dr. N. A. V. Piercy, Mr. D. R. Pye, Mr. W. P. Savage, Mr. O. E. Simmonds, Mr. H. E. Wimperis and Mr. L. A. Wingfield (Solicitor).

Among the business discussed was the following:—The Report of the Finance Committee; Report of the Grading Committee; Report of the Referees on the R.38 Memorial Prize Paper; suggested names for the Wilbur Wright Memorial Lecture, 1936; proposed Garden Party in 1936; list of members whose subscriptions are in arrear.

Election of Members

The following members were elected at the meeting of Council held on December 10th, 1935:—

Fellow.—Magnus Herman Volk (from Associate Fellow).

Associate Fellows.—Charles Moberly Barter, Bernard Arthur Duncan, Clifford Moore.

Associate Member.—Robert Walter.

Associates.—Richard Cox Abel, Cyril Henry Arthur Colman, Charles Brian Field.

Students.—John Leonard Burbidge, Karl Antony de Lisser, Kenneth Raymond Dixon, Henry Charles Horton Gurney, Thomas Anderson Jones, Kyoichi Nosawa, Henry Ernest James Rochfort, Ernest Edwin Robertson, Frank Tyson.

Companion.—Gerald Bonnaud.

Southampton Branch of the Society

A Branch of the Society has been formed in Southampton under the Chairmanship of Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S. The Honorary Secretary, to whom all communications should be sent is S. Scott-Hall, Esq., A.C.G.I., M.Sc., D.I.C., A.F.R.Ae.S., c/o The Supermarine Aviation Works (Vickers), Limited, Woolston, Southampton.

The Inaugural Lecture was given by the President of the Society, Lieut.-Colonel J. T. C. Moore-Brabazon, on October 30th, 1935. The subject chosen was "Whither Aviation," which the lecturer illustrated with a number of lantern slides. An interesting programme of lectures has been arranged for the New Year.

Portsmouth Branch of the Society

The Inaugural Lecture before the Portsmouth Branch was given by the Secretary of the Society, Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on October 24th, on "The Stratosphere." The following are officers of the Branch:—

President: A. Hessell Tiltman, Esq., B.Sc., F.R.Ae.S.
Chairman: F. Radcliffe, Esq., B.Sc., A.F.R.Ae.S.
Honorary Secretary: H. Irvin Birds, Esq., B.Sc., A.F.R.Ae.S., Park Mount, Kent Road, Southsea.

Notices of lectures to be read before the branch will appear in the green notices each month.

Subscriptions

Members are reminded that their subscriptions were due on January 1st, 1936. The Council hope that every member will make every effort to pay his subscription as early as possible. The rates are:—

	Home.			Abroad.		
	£	s.	d.	£	s.	d.
Fellow	4	4	0	3	3	0
Member	4	4	0	3	3	0
Associate Fellow	3	3	0	2	2	0
Associate Member	3	3	0	2	2	0
Associate	*2	2	0	*2	2	0
Student	1	1	0	1	1	0
Companion	2	2	0	2	2	0
Founder Member	2	2	0	2	2	0

*£1 1s. 0d. without Journal.

Acknowledgments

The Council acknowledge with grateful thanks the gift of old papers of historical value from Mr. H. R. Gillman, Secretary of the Society of British Aircraft Constructors.

The Council also wish to acknowledge the gift of a complete set of Scientific and Technical Publications of the French Air Ministry from the Director. These publications will be of great interest to members of the Society and they are filed in the Library for reference purposes should members wish to consult them.

Students' Section

The following is a list of Officers and Committee of the Students' Section for 1935-1936:—

Chairman: C. H. Jackson, Esq., B.Sc., A.C.G.I., D.I.C.
Vice-Chairman: R. L. Lickley, Esq., B.Sc.
Hon. Secretary: H. Leaderman, Esq., B.A., B.Sc. (Eng.).
Committee: A. H. Yates, A. F. Walsh, B.Sc. (Eng.), R. M. Barry, B. R. Siminson.

Binding of Journals

Arrangements have been made for members' Journals to be bound at the special price of 4s. 6d. per volume for the current volume and 5s. 6d. for back volumes. Journals should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the cost to the Society.

Additions to the Library

Technical Reports of the National Advisory Committee for Aeronautics:—

No. 507. Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. VI. Wings and Nacelles with Pusher Propeller. Donald H. Wood and Carlton Bioletti.

No. 518. The Drag of Airplane Wheels, Wheel Fairings and Landing Gears. II. Non-Retractable and Partly Retractable Landing Gears. David Biermann and W. H. Herrnstein, Jr.

No. 520. A Comparison of Fuel Sprays from Several Types of Injection Nozzles. Dana W. Lee.

No. 522. The Drag of Airplane Wheels, Wheel Fairings and Landing Gears. III. W. H. Herrnstein and David Biermann.

No. 529. A Flight Investigation of the Spinning of the F4B-2 Biplane with Various Loads and Tail Surfaces. N. F. Scudder and Oscar Seidman.

No. 533. Distribution and Regularity of Injection from a Multi-Cylinder Fuel Injection Pump. A. M. Rothrock and E. T. Marsh.

No. 535. Hydrogen as an Auxiliary Fuel in Compression Ignition Engines. Harold C. Gerrish and H. H. Foster.

No. 536. Wind Tunnel Tests of a 10-Foot Diameter Gyroplane Rotor. John B. Wheatley and Carlton Bioletti.

No. 537. Tests in a Variable Density Wind Tunnel of Related Airfoils Having the Maximum Camber Unusually Far Forward. Eastman N. Jacobs and Robert M. Pinkerton.

No. 538. Altitude Pressure Tables Based on the United States Standard Atmosphere. W. G. Brombacher.

No. 539. Investigation of Full-Scale Split Trailing Edge Wing Flaps with Various Chords and Hinge Locations. Rudolf Wallace.

Technical Notes of the N.A.C.A.:—

No. 539. Aerodynamic Characteristics of Several Airfoils of Low Aspect Ratio. C. H. Zimmerman.

No. 540. A Deflection Formula for Single-Span Beams of Constant Section Subjected to Combined Axial and Transverse Loads. Walter F. Burke.

No. 541. The Effect of the Angle of Afterbody Keel on the Water Performance of a Flying Boat Hull Model. John M. Allison.

No. 542. The Initial Torsional Stiffness of Shells with Interior Webs. Paul Kuhn.

No. 543. The Compressibility Burble. John Stack.

No. 544. An Application of the von Kármán-Millikan Laminar Boundary Layer Theory and Comparison with Experiment. A. E. von Doenhoff.

No. 545. Tank Tests of a Model of a Flying Boat Hull having a Longitudinally Concave Planing Bottom. J. B. Parkinson.

Journal of the Society of Aeronautical Science of Nippon, Volume II, No. 8, November, 1935.

Science Reports of the National Tsing Hua University, Series A, Mathematical and Physical Sciences, Volume III, No. 2.

Scientific Papers of the Institute of Physical and Chemical Research, Nos. 607-609.

Bulletin of the Institute of Physical and Chemical Research, Volume XIV, No. 11.

Proceedings of the International Conference on Civil Aeronautics, Washington, D.C., December 12-14, 1928.

The Development of the Heavy Oil Engine for Ship Propulsion. Eng. Cmdr. C. J. Hawkes.

Tin and its Uses; Tin and Civilisation. Miscellaneous Publications of the International Tin Research and Development Council, Nos. 4 and 5.

Technical Publications of the International Tin Research and Development Council:—

No. 22. Improvement in the Quality of Tinplate by Superimposed Electro-deposition of Tin. A. W. Rothersall and W. N. Bradshaw.

No. 23. Striations in Tin Coatings on Copper. Bruce Chalmers and W. D. Jones.

No. 24. The Atmospheric Corrosion and Tarnishing of Tin. L. Kenworthy.

No. 25. Electro-deposition of Tin Alloys from Alkaline Stannate Baths. R. G. Monk and H. J. T. Ellingham.

No. 26. The Mechanical Properties of Tin-Base Alloys. D. J. Macnaughtan and B. P. Haigh.

No. 27. The Electro-deposition of Bronze, Using Bronze Anodes. S. Baier and D. J. Macnaughtan.

No. 28. The Electro-deposition of Bronze, Using Bi-Metallic Anodes. D. J. Macnaughtan and C. Bechard.

The Care and Maintenance of a Modern Diesel-Engined Tanker Fleet. H. S. Humphreys.

Report of the Annual General Meeting of Imperial Airways, Limited.

Experiments with a Telephotometer. The Dependence of Extinction Coefficient upon Wave-Length. W. E. Middleton.

The Principles Underlying the Choice of Visibility Marks. W. E. Middleton.

Air Transport in Great Britain—Some Problems and Needs. Lieut.-Colonel F. C. Shelmerdine. (The Inaugural Brancker Memorial Lecture, Institute of Transport.)

Modern Methods of Air Survey and Exploration. H. Hemming.

Aviation Training. United States Department of Commerce.

Civil Aeronautics in the United States. Aeronautics Bulletin No. 1. United States Department of Commerce.

Further Progress in Controlled Cooling of Radial Aircraft Engines. J. M. Shoemaker. (Reprinted from the S.A.E. Journal.)

The Heterogeneity of Steel Ingots. Dr. W. H. Hatfield.

Repertorium Technicum, Volume IV, Nos. 9 and 10.

British Polar Year Expedition to Fort Rae, North-West Canada, 1932-1933. J. M. Stagg. Smithsonian Publication No. 3308.

Handbuch der Meteorologischen Instrumente und ihrer Auswertung. Professor Dr. E. Kleinschmidt.

Stratosphere and Rocket Flight. 2nd Edition. Chas. G. Philp.

High Speed Diesel Engines. A. W. Judge. 2nd Edition.

Technical Aerodynamics. Karl D. Wood.

With Plane, Boat and Camera in Greenland. Dr. Ernst Sorge.

The Book of Speed. 2nd Edition.

North to the Orient. Anne Morrow Lindbergh.

Encyclopædia of Aviation. Squadron Leader C. G. Burge.

Jane's All the World's Aircraft. Edited by C. G. Grey.

Symposium of the Welding of Iron and Steel, Volume I and Volume II, Iron and Steel Institute.

Proceedings of the Institute of Mechanical Engineers, Volume CXXIX.
Publications Scientifiques et Techniques du Ministere de l'Air. Service des Recherches de l'Aeronautique, Nos. 1 to 73 (1930-1935).

Forthcoming Events

Jan. 2nd.—Lecture before the Yeovil Branch, by Dr. H. J. Gough, on "The Work of the Engineering Department of the N.P.L."

Jan. 2nd.—Lecture before the Portsmouth Branch, by Mr. C. B. Carr, on "Commercial Design of Aircraft Wireless Equipment."

Jan. 6th.—Lecture before the Society, by Mr. J. E. Hodgson, Hon. F.R.Ae.S., on "Sir George Cayley," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6.30 p.m. Light refreshments will be served between 6 and 6.30 p.m.

Jan. 7th.—Lecture before the Bristol Branch, by Mr. W. J. Richards, on "Aircraft Instruments."

Jan. 9th.—Informal Discussion by the Students' Section in the Library, at 7, Albemarle Street, W.1, at 7 p.m., on "Stressed Skin Construction." Chairman: C. H. Jackson, B.Sc., A.C.G.I., D.I.C.

Jan. 16th.—Lecture before the Manchester Branch, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "The Stratosphere."

Jan. 16th.—Lecture before the Portsmouth Branch, by Mr. H. B. Irving, B.Sc., F.R.Ae.S., on "Wing Flaps."

Jan. 16th.—Film Display before the Yeovil Branch, "The Development of the Lathe," and three other films.

Jan. 18th.—Students' Section Visit to the de Havilland Aircraft Works, Hatfield.

Jan. 20th.—Lecture before the Society, by Professor W. L. Bragg, O.B.E., M.A., Sc.D., F.R.S., on "The Theory of Alloy Structures," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6.30 p.m. Light refreshments will be served between 6 and 6.30 p.m.

Jan. 28th.—Lecture before the Bristol Branch, by Mr. A. H. R. Fedden, F.R.Ae.S., on "Future Research on Air-Cooled Aero Engines."

Jan. 28th.—Colloquialism by the Students' Section in the Library, at 7, Albemarle Street, W.1, at 7 p.m., on "The Technical and Scientific Aspects of the Design, Construction and Flying of Sailplanes." Chairman: S. Scott-Hall, A.C.G.I., D.I.C., M.Sc., A.F.R.Ae.S.

Jan. 30th.—Lecture before the Yeovil Branch, by Mr. C. H. Smith, on "Ball, Roller and Needle Bearings and their Manufacture."

Jan. 30th.—Lecture before Leys School, Cambridge, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "A Trip into the Stratosphere."

Feb. 2nd.—Lecture before Stonyhurst College, by Mr. F. R. G. Cook, B.Sc. (Eng.).

Feb. 3rd.—Lecture before the Society, by Dr. H. C. Watts, M.B.E., F.R.Ae.S., on "Airscrew Development," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6.30 p.m.

Feb. 8th.—Lecture before Herne Bay College, by Mr. E. W. Roberts.

Feb. 13th.—Lecture before the Portsmouth Branch, by Mr. G. H. Dowty, M.I.Ae.E., A.F.R.Ae.S., on "Undercarriage Developments."

Feb. 13th.—Lecture before the Yeovil Branch, by Mr. R. A. C. Brie, on "The Practical Use and Maintenance of the Autogiro."

Feb. 15th.—Lecture before Eastbourne College, by Mr. S. Scott-Hall, A.C.G.I., M.Sc., D.I.C., A.F.R.Ae.S.

Feb. 17th.—Lecture before the Society, by Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S., on "The Boundary Layer and Recent Developments," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6.30 p.m.

J. Laurence Pritchard, *Secretary*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

FEBRUARY, 1936

Address to H.M. King Edward VIII

The following address, signed by the President of the Society, has been forwarded to H.M. the King:—

To His Majesty King Edward VIII, of the United Kingdom of Great Britain, Ireland and of the British Dominions beyond the Seas, Defender of the Faith, Emperor of India.

May it please Your Majesty, We, your most dutiful and Loyal Subjects, the President, Council, and Members of the Royal Aeronautical Society of Great Britain, beg leave humbly to offer our condolence to Your Majesty on the great sorrow you have sustained in the death of our beloved Sovereign, the late King, and respectfully to assure you of our unswerving loyalty and devotion to Your Majesty's person.

Meeting of Council

A Meeting of the Council was held in the Offices of the Society on Tuesday, January 21st, 1936.

Present: Lieut.-Colonel J. T. C. Moore-Brabazon in the chair at the commencement of the meeting; Mr. D. R. Pye in the chair for the latter part of the meeting; Captain P. D. Acland, Major J. C. Buchanan, Major G. P. Bulman, Mr. R. S. Capon, Mr. H. Roxbee Cox, Mr. S. Scott-Hall, Professor F. T. Hill, Professor G. T. R. Hill, Captain A. G. Lamplugh, Mr. W. O. Manning, Dr. N. A. V. Piercy, Mr. E. F. Relf.

Among the business discussed was the following:—Wilbur Wright Lecturer for 1936; R.38 Memorial Prize Paper; Report of the Finance Committee; Report of the Grading Committee; the Segrave Trophy; Lectures for 1936-1937 Session; Broadcast Talk on the Designer's Task; use of the Society's notepaper by members; Chairmanship of the Education and Examinations Committee; Appointment of Representative on the Council of the British Gliding Association; Appointment of Representatives on the Advisory Committee for Aeronautical Engineering of the City and Guilds of London Institute.

Election of Members

The following recommendations of the Grading Committee were approved by the Council at a meeting held on January 21st, 1936:—

Fellows.—A. Francis Arcier, Harold John Pollard, Bernard William Shilson.

Associate Fellows.—Herbert Reginald Carefoot, Roger Lander Ninnes, Edwin Shipley, Herbert Brian Squire, James William Philip Uren, Alfred Richard Weyl, Howard Arthur Wills.

Associate Members.—Esmond Brown, F. G. Boreham, William Goodridge, Jai Singh.

Associates.—William Courtenay, G. C. Datta, Reginald Ernest Gustine, R. C. Manocha, G. W. Nunn, J. J. E. Sloan, Nigel Tangye.

Students.—C. G. Allington, William Armstrong, H. J. Campton, David Gilbert, M. H. Gordon, Miss B. Etty Leal, Edward John Mann, G. E. Marshall, W. J. Morton, C. J. Titler, D. D. Fenton Smith, J. A. C. Williams, G. E. L. Wray, A. D. Young.

Companions.—J. B. Bayas, M. G. Casey, S. J. Davies, W. M. Mackinlay, M. K. Paranjpye.

Election of Council

Attention is drawn to Rules 68-85 regulating the constitution of the Council, and in particular to Rules 79 and 81, which read as follows:—

RULE 79.—One half of the Council (excluding the President and the Immediate Past-President if a member of Council) shall retire annually. The members who shall retire shall be those longest in office, except as provided in Rule 85. Retiring members of Council who have served two terms in succession (four years) shall not be eligible for re-election until the next annual election, when they will be eligible.

RULE 81.—Nominations of candidates for election to the Council must be received by the Secretary not less than twenty-one days before the Annual General Meeting, with an intimation in writing by the candidates that they are willing to serve. Nominations must be signed by one supporter and two seconders, who must each be entitled to vote in the R.Ae.S.I.

Under Rule 105 the Annual General Meeting is held at some convenient date before the end of March of each year, so that nominations must be received during the first week in March, and preferably by March 1st at the latest.

R.38 Memorial Prize

The R.38 Memorial Prize has been awarded to Captain J. Morris for his paper on "The Stressing of Rigid-Jointed Frames." The paper will be published in a future issue of the *Journal*.

Associate Fellowship and Associate Membership Examinations

The next examinations will be held at 7, Albemarle Street, W.1, in May, 1936. Application forms, obtainable from the Secretary, should be sent in with entrance fees not later than March 31st. Applications received after that time will not be considered valid.

The following candidates were successful at the December, 1935, examinations:—

ASSOCIATE FELLOWSHIP EXAMINATION.

L. G. Byrne	Theory of Internal Combustion Engines. Aircraft Materials.
H. A. Craw	Applied Mathematics. Theory of Internal Combustion Engines (1st Place). Aircraft Materials (1st Place).
W. E. Crook	Theory of Internal Combustion Engines. Wireless Telegraphy and Telephony.
A. H. Denny	Design (Aero Engines).
E. G. Gregson ...	Pure Mathematics (Commended). Strength of Materials and Structures. Aerodynamics (Commended).

N. Grossman	Applied Mathematics. Theory of Internal Combustion Engines. Design (Aero Engines).
J. C. Hardman ...	Strength of Materials and Structures.
V. A. M. Hunt ...	Applied Mathematics. Theory of Internal Combustion Engines. Aircraft Materials.
C. P. L. Nicholson ...	Aerodynamics.
P. N. Willoughby ...	Navigation and its Application to Aeronautics.

ASSOCIATE MEMBERSHIP EXAMINATION.

P. H. Campton	Theory of Internal Combustion Engines. Aircraft Materials.
P. N. Cunningham ...	Applied Mathematics. Theory of Internal Combustion Engines. Aircraft Materials.
K. R. Dixon	Applied Mathematics. Theory of Internal Combustion Engines. Aircraft Materials.
E. O. Draper	Applied Mathematics. Theory of Internal Combustion Engines (1st Place). Aircraft Materials (1st Place, Commended).
J. D. Gordon	Theory of Internal Combustion Engines. Aircraft Materials.
M. H. Gordon... ...	Applied Mathematics. Theory of Internal Combustion Engines. Aircraft Materials.
H. T. Grigg	Applied Mathematics. Theory of Internal Combustion Engines. Aircraft Materials.
I. H. List	Applied Mathematics (Commended). Theory of Internal Combustion Engines. Aircraft Materials.
G. N. F. Luckie ...	Applied Mathematics (1st Place, Commended). Theory of Internal Combustion Engines. Aircraft Materials.
R. C. Morgan ...	Applied Mathematics. Strength of Materials and Structures.
G. P. L. Pardoe ...	Applied Mathematics. Theory of Internal Combustion Engines. Aircraft Materials.
R. L. Smyth	Applied Mathematics. Aircraft Materials.
M. K. Tha	Applied Mathematics. Theory of Internal Combustion Engines.

Endowment Fund

The Council gratefully acknowledge for the sixth year in succession a donation of £1 1s. 0d. from Mr. A. J. Henington, Associate Member. Mr. Henington has consistently contributed to the Endowment Fund since the general appeal was first made.

It is difficult to exaggerate the importance of the Endowment Fund on the future of the Society. The Council have made every effort to keep the entrance fees and annual subscriptions of members as low as possible, with the result that it has not been possible to create rapidly a large reserve fund.

The time appears to be approaching when the Society will be faced with a definite scheme for a building of its own, and it will have to come to a decision whether to continue in its present premises or to take the bold forward step, coming into line with every other influential society, of owning its own building and having its own lecture theatre. Such a step would enhance greatly the already high prestige of the Society and would bring many facilities to members which cannot now be made available.

The acceptance or rejection of the scheme at present under consideration may turn upon very little. It is hoped that every member will give the Endowment Fund his or her serious consideration and will contribute what they can within their means towards it. Every sum, however small, will be acknowledged in the Journal and will be strictly allocated, under the terms of the Endowment Fund Trust Deed, to a new building for the Society and to no other object.

If the example of Mr. Henington had been followed Air House would now be in being.

Discussion on "Metallic Wear"

A General Discussion on "Metallic Wear" is being arranged by the Institute of Metals, to take place on March 10th, 1936, at 7.30 p.m., at the Institution of Mechanical Engineers, Storey's Gate, S.W.1. The discussion will be opened by Dr. H. W. Brownsdon with a paper which reviews some of the major factors involved in metallic wear and indicates a method by which they can be quantitatively assessed. Members of the Society are invited to attend and take part in the discussion if they wish. Advance copies of the paper by Dr. Brownsdon may be obtained on application to the Secretary of the Institute of Metals, 36, Victoria Street, Westminster, S.W.1.

Use of the Society's Notepaper by Members

The Council have had a letter from a member inquiring as to the legitimate use of the Society's notepaper or address. The inquiry was particularly directed towards giving the Society's address when writing a letter to a newspaper for publication.

The Council wish to draw the attention of all members that the use of the Society's address is mainly to enable members to have letters sent to headquarters for forwarding when they have no permanent address. It must not be used for business purposes or in any way which might imply that the letter which a member has written has the authority, implied or otherwise, of the Society behind it.

Additions to the Library

Reports and Memoranda of the Aeronautical Research Committee:—

No. 1636. Tests on Aerofoil Flaps in the Compressed Air Tunnel. R. Jones, A. H. Bell and E. Smyth.

No. 1659. Split Flaps and Other Devices for Facilitating Landing. S. B. Gates.

No. 1664. Note on Boundary Layer Flow. H. B. Squire.

No. 1665. Rolling and Yawing Moments on Half Wings with Various Modifications of Wing Tips. D. H. Williams.

No. 1667. A Distribution Method of Stress Analysis. Prof. J. F. Baker and A. J. Ockleston.

No. 1674. Tables for Use in an Improved Method of Airscrew Strip Theory Calculation. C. N. H. Lock and D. Yeatman.

Theory of Machines, Third Edition. Louis Toft and A. T. J. Kersey.

Learning to Fly, Fourth Edition. Frank A. Swoffer.

Aero Engines ("D" Licence), Third Edition. A. N. Barrett.

La Navigation Aérienne Simplifiée. Lieut. F. D'Autheville.

L'Aviation de Montagne, by Capitaine Seive and General Dosse.

Le Mont-Blanc Aérien. Géneral Benoist et Capitaine Seive.

With Plane, Boat and Camera in Greenland. Dr. Ernst Sorge.

North to the Orient. Anne Morrow Lindbergh.

Andrew Carnegie, the Trusts and their Work.

On the Colours of Distant Objects and the Visual Range of Coloured Objects. W. E. Knowles Middleton.

The Climate of the Gulf of St. Lawrence and Surrounding Regions in Canada and Newfoundland, as it Affects Aviation. W. E. Knowles Middleton.

Obituary

JOHN LORD, *Fellow*.

The Council record with the deepest regret the sudden death of Mr. John Lord. He was one of the most popular, respected and best beloved men in aviation and his loss will be felt in many ways for a long time to come. One of the early pioneers with A. V. Roe, John Lord saw aviation grow, and with its growth he became one of its outstanding figures. He joined the Society in 1912 and was elected a *Fellow* in 1928, and for many years was a member of the Finance Committee.

In a later issue of the *Journal* a greater tribute will be paid to his memory and his work. Here we can only say that John Lord made no enemies and innumerable friends, all of whom will regret the death of one of aviation's great men.

Forthcoming Events

Feb. 1st.—Lecture before Sherborne School, by Mr. H. J. Penrose, A.F.R.Ae.S., on "A Trip into the Stratosphere."

Feb. 2nd.—Lecture before Stonyhurst College, by Mr. F. R. G. Cook, B.Sc. (Eng.), on "How an Aeroplane is Made and Flies."

Feb. 3rd.—Lecture before the Society, by Dr. H. C. Watts, M.B.E., F.R.Ae.S., on "Airscrew Development," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6.30 p.m.

Feb. 5th.—Lecture before Upton College, by Mr. E. W. Roberts, on "A Trip into the Stratosphere."

Feb. 7th.—Lecture before Manchester Grammar School, by Captain J. L. Pritchard, Hon. F.R.Ae.S., on "The Imperial Air Routes."

Feb. 8th.—Lecture before Herne Bay College, by Mr. E. W. Roberts, on "A Trip into the Stratosphere."

Feb. 8th.—Students' Section, Visit to the Works of High Duty Alloys, Limited, Slough, Bucks.

Feb. 12th.—Lecture before the Southampton Branch, by Mr. Dorey, on "The Modern Trend of the Liquid-Cooled Engine Installation."

Feb. 13th.—Lecture before the Portsmouth Branch, by Mr. G. H. Dowty, M.I.Ae.E., A.F.R.Ae.S., on "Undercarriage Developments."

Feb. 13th.—Lecture before the Students' Section, in the Library, at 7, Albemarle Street, W.1, at 7 p.m., by Dr. N. A. de Bruyne, on "The Design and Construction of a Light Aeroplane."

Feb. 13th.—Lecture before the Yeovil Branch, by Mr. R. A. C. Brie, on "The Practical Use and Maintenance of the Autogiro."

Feb. 15th.—Lecture before Eastbourne College, by Mr. S. Scott-Hall, B.Sc., D.I.C., A.F.R.Ae.S.

Feb. 15th.—Lecture before Mostyn House School, by Mr. F. R. G. Cook, B.Sc. (Eng.), on "The Imperial Air Routes."

Feb. 17th.—Lecture before the Society, by Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S., on "The Boundary Layer and Recent Developments," in the Lecture Hall of the Institution of Electrical Engineers, Victoria Embankment, W.C.2, at 6.30 p.m.

Feb. 18th.—Lecture before Frensham Heights School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "How an Aeroplane is Made and Flies."

Feb. 18th.—Lecture before the Bristol Branch, by Mr. Norman Edgar, on "Aircraft Operating."

Feb. 20th.—Lecture before the Coventry Branch, by Mr. T. E. Beacham, B.Sc., A.M.I.Mech.E., on "Variable Pitch Propellers."

Feb. 18th.—Lecture before the Scottish Society, Walton, by Mr. J. T. Morton, A.M.I.Ae.E.

Feb. 21st.—Lecture before the Technical Institute, Rochester, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "Training R.A.F. Pilots."

Feb. 25th.—Lecture before St. Paul's School, Kensington, by Mr. H. T. Winter, on "A Trip into the Stratosphere."

Feb. 25th.—Lecture before the Students' Section, in the Library, at 7, Albemarle Street, W.1, at 7 p.m., by Mr. W. Tye, B.Sc., on "The Mechanical Testing of Aircraft Structures and Components."

Feb. 25th.—Lecture at Newport, Isle of Wight, by Mr. T. H. Lloyd, on "The History of the Aeroplane."

Feb. 27th.—Lecture before the Yeovil Branch, by Mr. Slee, of Shell Mex, Limited, on "Development of Fuel and Lubricating Oils."

Feb. 27th.—Lecture before the Portsmouth Branch, by Mr. S. J. Nightingale, on "Duralumin and Elektron."

Feb. 27th.—Lecture before Northampton Town and County School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "A Trip into the Stratosphere."

Feb. 28th.—Lecture before Willaston School, Nantwich, by Mr. F. R. G. Cook, B.Sc. (Eng.), on "A Trip into the Stratosphere."

Feb. 28th.—Lecture before Haberdashers' Aske's Hampstead School, by Mr. C. H. Jackson, B.Sc., A.C.G.I., D.I.C., on "A Trip into the Stratosphere."

Feb. 28th.—Lecture before Leighton Technical College, by Mr. S. J. Cox, B.Sc., on "The History of the Aeroplane."

March 5th.—Lecture before the Students' Section, in the Library, at 7, Albemarle Street, W.1, at 7 p.m., by Mr. W. S. Coleman, B.Sc., on "Airflow Experiments in Flight and in the Wind Tunnel." (Illustrated by a film taken during flight by Mr. Coleman.)

March 6th.—Lecture before Clayesmore School, Iwerne Minster, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "How an Aeroplane is Made and Flies."

March 7th.—Students' Section, Visit to Hanworth Aerodrome.

March 11th.—Lecture before the Southampton Branch, by Mr. Lobelle, on "American Aircraft Design."

March 13th.—Lecture before the Yeovil Branch, by Mr. Ivor McClure, D.S.O., on "Air Routes."

J. Laurence Pritchard, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

MARCH, 1936

Annual General Meeting

NOTICE IS HEREBY GIVEN THAT THE ANNUAL GENERAL MEETING of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, will be held on Monday, March 30th, 1936, at 6.30 p.m., at the Offices of the Society, 7, Albemarle Street, London, W.1.

AGENDA.

1. To appoint scrutineers of the Council Ballot.
2. To receive and deliberate upon the Report of the Council on the state of the Society, and the Balance Sheets of Aerial Science, Limited, and Aeronautical Trusts, Limited, as printed in the Journal of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, for March, 1936.
3. To receive the names of those elected to fill the vacancies on the Council for the years 1936-1938.
4. To elect the Auditors for the ensuing year for Aerial Science, Limited, and Aeronautical Trusts, Limited.
5. To consider any other business.

Garden Party

The President and Council will hold a Garden Party on Sunday, May 10th, 1936. The Garden Party will be held, by kind permission of the Past-President, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., at the Great West Aerodrome, near Hayes, Middlesex. It will be on the same general lines as the immensely successful party of last year. Full particulars will be announced in the April and May Journals.

Wilbur Wright Memorial Lecture and Reception

The Wilbur Wright Memorial Lecture and Reception will be held in the Science Museum, Aeronautical Section, on May 21st, by kind permission of the Director, Colonel E. E. B. Mackintosh. The lecturer will be Mr. D. R. Pye, M.A., M.I.Mech.E., F.R.Ae.S.

This year is the 70th anniversary of the founding of the Society and arrangements are being made to show, on the night of the lecture, and for a month afterwards, a special Royal Aeronautical Society's exhibit of aeronautical objets d'art, aeronautical trophies, medals, engravings, etc., and rare or unique articles, as for example, the first aviation passport issued in 1836.

The Council are very anxious to make its exhibit as widely varying and as interesting as possible. Already many offers have been received for the loan of various articles and the Council would welcome the opportunity of obtaining any others on loan. They will all be shown in cases and every care taken of them. Those who have anything of aeronautical interest should write in the first place to the Secretary.

Election of Council

Attention is drawn to Rules 68-85 regulating the constitution of the Council and in particular to Rules 79 and 81, which reads as follows:—

> RULE 79.—One half of the Council (excluding the President and Immediate Past-President if a Member of Council) shall retire annually. The members who shall retire shall be those longest in office, except as provided in Rule 85. Retiring Members of Council who have served two terms in succession (four years) shall not be eligible for re-election until the next annual election, when they will be eligible.
>
> RULE 81.—Nominations of candidates for election to the Council must be received by the Secretary not less than twenty-one days before the Annual General Meeting, with an intimation in writing by the Candidates that they are willing to serve. Nominations must be signed by one supporter and two seconders, who must be entitled to vote in the R.Ae.S.I.

Nominations of Candidates for election to the Council must be received by the Secretary on or before Monday, March 9th, 1936.

Council Meeting

A Meeting of the Council was held on Tuesday, February 11th, 1936.

Present:—In the chair, Lieut.-Colonel J. T. C. Moore-Brabazon (President); Captain P. D. Acland, Major G. P. Bulman, Mr. H. Roxbee Cox, Mr. E. C. Gordon England, Mr. S. Scott-Hall, Professor G. T. R. Hill, Mr. J. E. Hodgson, Major D. H. Kennedy (Honorary Treasurer), Mr. W. O. Manning, Major R. H. Mayo, Dr. N. A. V. Piercy, Mr. W. P. Savage, Mr. H. E. Wimperis.

Among the business discussed was the following:—Report of the Finance Committee; report of the Grading Committee; the proposed Air House; appointment of representative on the Engineering Joint Council; Wilbur Wright Memorial Lecture and Reception; Draft Annual Report of the Council for the year 1935-1936; Date for the Annual General Meeting; Date for the Garden Party.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on February 11th, 1936:—

Fellow.—William Donald Douglas.

Associate Fellows.—Luis de Florez, Howard Trethewen Edgecombe, Geoffrey Fraser Wallace.

Associate Members.—George Frederick Halliday, James Victor Saunders.

Associates.—Ralph Charles Pike, Alexander Symon, Percival Nesbit Willoughby.

Students.—John Dennis Graham, William Alan Kenneth Grant, Denys Marsh Gulliver-Cradwick, John Hardenberg, William Jackson, Robert Dove Leakey, George Noel Fraser Luckie, Alfred Lipfriend, William John Adams Luscombe, H. A. Skeats, K. M. Smith, Maung Kyaw Tha, Peter Clarkson Wise.

Companions.—Miss Alice Kennedy, James Leonard Barnard Jones.

Additions to the Library

Statistical Theory of Turbulence, by Professor G. I. Taylor, F.R.S. (Proceedings of the Royal Society, No. 873.)

Distribution of Velocity and Temperature between Concentric Cylinders, by Professor G. I. Taylor, F.R.S. (Proceedings of the Royal Society, No. 874.)

Machine Drawing for Students, by F. J. Pryer.

How to Build Flying Boat Hulls and Seaplane Floats, by J. Streeter.

Aero Engines, Inspection of, During Manufacture, Overhaul and Test ("D" Licence), by A. N. Barrett.

Andrew Carnegie. The Trusts and their Work.

Learning to Fly, F. A. Swoffer (4th Edition).

V.D.I. Jahrbuch, 1936.

Engineering Abstracts of the Institution of Civil Engineers, New Series, No. 66.

Transactions of the Institute of Patent Agents, Volume LIII, Session 1934-35.

Journal of the Institute of Metals, Volume LVII, No. 2, 1935.

R. and M. No. 1619. Torsion of a Rectangular Tube with Axial Constraints, D. Williams.

Air Navigation Bill, 1935.

The World's Airway System, J. A. Wilson.

Forthcoming Events

March 5th.—Lecture before the Students' Section, in the Library, at 7, Albemarle Street, W.1, at 7 p.m., by Mr. W. S. Coleman, B.Sc., D.I.C., A.C.G.I., on "Visual Methods of Observing Flow." The lecture will be illustrated by lantern slides and films.

March 6th.—Lecture before Clayesmore School, Iwerne Minster, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "How an Aeroplane is Made and Flies."

March 7th.—Students' Section, Visit to Hanworth Aerodrome.

March 3rd.—Lecture before the Gloucester and Cheltenham Branch, by Major C. J. Stewart, O.B.E., M.I.Mech.E., F.R.Ae.S., on "Recent Development of Instruments and Electrical Gear."

March 10th.—Meeting of Council, in the Library, at 5.30 p.m.

March 11th.—Lecture before the Southampton Branch, by Mr. M. Lobelle, on "American Aircraft Design."

March 13th.—Lecture before the Yeovil Branch, by Mr. Ivor McClure, D.S.O., on "Air Routes."

March 17th.—Lecture before the Gloucester and Cheltenham Branch, by Mr. G. H. Dowty, M.I.Ae.E., A.F.R.Ae.S., on "Retracting Undercarriages."

March 17th.—Lecture before the Bristol Branch, by Dr. G. P. Douglas, M.C., A.F.R.Ae.S., on "The 24ft. Wind Tunnel."

March 19th.—Lecture before the Manchester Branch, by Mr. T. G. Bradley, M.I.A.E., on "Modern Car Production Methods."

March 19th.—Lecture before the Coventry Branch, by Flt. Lieut. P. W. S. Bulman, F.R.Ae.S., on "Type Testing an Aircraft."

March 19th.—Lecture before the Students' Section, by Mr. R. C. Abel, A.R.Ae.S.I., on "The Monoplane Solution." Captain J. Laurence Pritchard, Hon. F.R.Ae.S., in the chair.

March 20th.—Lecture before the Barrow and District Association of Engineers, by Mr. F. R. G. Cook, B.Sc., on "Aircraft Construction."

March 21st.—Lecture before Highgate School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "A Trip into the Stratosphere."

March 23rd.—Lecture before the Society, by Mr. R. H. Dobson, on "The Jointing of Materials by Welding." The lecture will be held at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6.30 p.m. Light refreshments will be served between 6 and 6.25 p.m.

March 27th.—Lecture before the Yeovil Branch, by Mr. W. P. Savage, A.M.I.Aut.E., A.F.R.Ae.S., on "The 'Dagger' Aero Engine."

March 30th.—ANNUAL GENERAL MEETING of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, at 6.30 p.m., in the Library, at 7, Albemarle Street, W.1.

March 31st.—Lecture before the Gloucester and Cheltenham Branch, by Mr. M. Lobelle, on "American Aircraft Design."

March 31st.—Lecture before the Students' Section, by Mr. K. Seth-Smith, on "The Test Pilot's Job." Mr. D. L. Hollis Williams, A.F.R.Ae.S., in the chair.

April 11th.—Lecture before the Isle of Wight Natural History Society, by Mr. T. H. Lloyd, on "A Trip into the Stratosphere."

April 16th.—Lecture before the Coventry Branch, by Mr. J. E. Chorlton, on "Aircraft Instruments."

April 18th.—Visit by the Students' Section to the Royal Aircraft Establishment, South Farnborough.

April 20th.—Lecture before the Society, by Dr. H. Gough, M.B.E., F.R.S., and Mr. W. A. Wood, on "Strength of Materials Afforded by Modern Physics." The lecture will be held at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6.30 p.m. Light refreshments will be served between 6 and 6.25 p.m.

April 23rd.—Lecture before the Manchester Branch, by Flt. Lieut. H. F. Jenkins, on "Training for a Career in Aviation."

April 28th.—Lecture before the Students' Section, by Mr. J. L. B. Jones, B.Sc., on "The Application of Aerodynamics to Mechanical Engineering." Dr. G. V. Lachmann, A.F.R.Ae.S., in the chair.

J. LAURENCE PRITCHARD, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

APRIL, 1936

Easter Holidays

The Offices and Library of the Society will be closed for the Easter holidays from Friday, April 10th, to Monday, April 13th, inclusive.

Council Meeting

A Meeting of the Council was held on Tuesday, March 10th, 1936, in the Offices of the Society.

Present: Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair; Captain P. D. Acland, Major J. S. Buchanan, Mr. H. Roxbee Cox, Professor F. T. Hill, Professor G. T. R. Hill, Major D. H. Kennedy (Honorary Treasurer), Mr. W. O. Manning, Major R. H. Mayo, Mr. D. R. Pye, Mr. E. F. Relf, Mr. W. P. Savage, Mr. H. E. Wimperis (Vice-President), Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—Wilbur Wright Memorial Lecture; Report of the Grading Committee; Report of the Finance Committee; appointment of a representative on a Committee to administer a Sefton Brancker Memorial Fund; suggestions for the Brancker Memorial Lecture.

Garden Party, May 10th, 1936

On Sunday, May 10th, 1936, the President (Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P.) and the Council will hold a Garden Party at the Great West Aerodrome, near Hayes, the use of which has kindly been given to the Society for the day by the Immediate Past-President, Mr. C. R. Fairey, M.B.E., F.R.Ae.S.

The Garden Party will begin at 2.30 o'clock with a reception by the President and Council, after which members and their guests will have an opportunity of watching a flying display and interesting aircraft. Other arrangements will be announced as they are completed. By permission of the Air Council the Band of H.M. Royal Air Force will play during the afternoon, under the direction of Flight Lieutenant R. P. O'Donnell, M.V.O., Director of Music, R.A.F.

The President and Council extend a special welcome to ladies at the Garden Party.

Last year there were so many applications for tickets at the last minute that it was found impossible to supply them all. It will very greatly help the work of the staff if members will make application as early as possible.

Tickets, including tea, are 5s. each. Applications for tickets must be received by Thursday, May 7th, at the latest.

Wilbur Wright Memorial Lecture

The Wilbur Wright Memorial Lecture for 1936 will be delivered by Mr. D. R. Pye, M.A., M.I.Mech.E., F.R.Ae.S., on Thursday, May 21st, 1936, in the Science Museum, South Kensington, by kind permission of the Director, Colonel E. E. B. Mackintosh. The title of the lecture is " Slippery Surfaces."

This year is the 70th anniversary of the founding of the Society and arrangements are being made to show, on the night of the lecture, and for a month afterwards, in the Museum, by kind permission of the Director, a special Royal Aeronautical Society's exhibit of aeronautical objets d'art, aeronautical trophies, medals, engravings, etc., and rare or unique articles, as for example, the first aviation passport issued in 1836.

The Council are very anxious to make its exhibit as widely varying and as interesting as possible. Already many offers have been received for the loan of various articles and the Council would welcome the opportunity of obtaining any others on loan. They will all be shown in cases and every care taken of them. Those who have anything of aeronautical interest should write in the first place to the Secretary.

Election of Members

The following recommendations of the Grading Committee were approved by the Council at their meeting on March 10th, 1936:—

Fellow.—Walter Potter Savage (from Associate Fellow).

Associate Fellows.—Edward George Fischeles (from Student), Eric Pyke, David Llewelyn Ellis, Thomas Swinden, James Alfred Wells.

Associates.—Abdul Khan Majeed, Charles Harry Smith, Walter Noble Twelvetrees, Charles James Walker, Ronald John Knights-Whittome (from Student).

Students.—Kenneth Alfred Mackay Baldry, Victor Brussovansky, John Noel Graydon-Carter, Jayaram Dayaram, Imrie Dodd, Harold Michael Gardiner, Hugh McLennan Kendall, John Lansdell, Derek Charles Palmer, Gordon Ernest Rose, Edgar Allen Stroud, Donald Crawford Wood.

Companions.—John Bingham Emmott, Colin James Craig Ewing (from Student), John Parkyn Jeffcock.

Subscriptions

Under the Rules, members who have not paid their subscriptions for the current year by April 1st are not entitled to have the Journal sent to them. It is not always possible to send back numbers of the Journal to those who pay their subscriptions some time after April 1st, as many of the Journals go out of print.

The Council wish to thank all those members who have been prompt in paying their subscriptions. By the members supporting the Society in this way it is possible to legislate ahead and make arrangements which effect considerable saving against having to work from month to month.

Income Tax

In response to numerous inquiries with regard to a rebate on Income Tax for their subscriptions, the following is a copy of a letter received from the Principal Inspector of Taxes:—

" Ref. H.R.S. 34/C.I. 4420/63. 18/8/28.

Dear Sir,—Further to your interview with Mr. Stoneley at this office on the 19th July, I am now in a position to inform you that the Board of

Inland Revenue will not raise objection to the allowance as an expense for Income Tax purposes of annual subscriptions paid by members who are:—

(i) Assessable under Schedule D of the Income Tax Acts in respect of professional or trading profits, subject to the decision of the Commissioners who make the assessment that such subscriptions are sufficiently closely related to the business carried on; or

(ii) Assessable under Schedule E in those cases only in which continual membership of the Society is an essential condition of the terms of appointment.

Yours faithfully,

(Signed) GEO. WILCOCK,

Principal Inspector of Taxes."

Membership Badges

For those members of the Society who wish to have them, a badge has been prepared. The badge shows the symbols of the Society, the peregrine and balloon, in finely chased gilt on a blue enamel background, surrounded by a royal blue border on which appears the lettering "The Royal Aeronautical Society, 1866." The badges are hand made with the greatest care so that they will always retain their original appearance, and it is hoped that members will wear them on all suitable occasions.

Members of the Society may obtain badges from the Offices at 7, Albemarle Street for wearing in the lapel of the coat, price 5s. 3d. post free.

Associate Fellowship and Associate Membership Examinations

The next Associate Fellowship and Associate Membership Examinations will be held in the Offices of the Society on Tuesday, May 26th, and Wednesday, May 27th, 1936. The Library will be closed on both days.

"Aircraft Engineering"

To help Students and Associates of the Society, the Editor of "Aircraft Engineering" has made available a specially reduced subscription rate of 21s. 0d. (post free) as against the normal subscription of 26s. 0d. (post free). These terms only apply to Students and Associates and application for the reduced subscription rate can be made either direct to the Editor of "Aircraft Engineering," 2, Bloomsbury Place, London, W.C.1, or through the Society.

Lecture for the Students' Section

A lecture before the Graduates' Section of the Institution of Automobile Engineers will be held on Thursday, April 16th, at 7.25 p.m., by Mr. R. A. Hall, on "The Estimation of Aircraft Performance." Students of the Society are invited to attend. Tickets are not necessary.

Acknowledgments

The Council acknowledge with grateful thanks Journals from the following members:—Mr. R. L. Howard-Flanders (Fellow), Miss G. Cottrell, Mrs. J. D. Fullerton.

The Council would also like to acknowledge with thanks a copy of "U.S.S.R. in Construction. The Eighteenth Year of the Revolution," by Maxim Gorki, presented by Mr. H. Leaderman.

Dr. F. W. Lanchester has presented to the Library a copy of his "Notes Concerning the Position of Aeronautics in 1908 when visiting the Continent

(Germany and France), September-October of that year." These contemporary notes are of very great interest in the light of modern knowledge and form a valuable addition to the Library.

The National Geographic Society, Washington, has kindly presented the Society with lantern slides of the stratosphere balloon " Explorer II," which will complete the stratosphere series of slides.

Additions to the Library

Technical Reports of the National Advisory Committee for Aeronautics, U.S.A.:—

No. 528. Reduction of Hinge Moments of Airplane Control Surfaces by Tabs, Thomas A. Harris.

No. 530. Characteristics of the N.A.C.A. 23012 Airfoil from Tests in the Full-Scale and Variable Density Tunnels, Eastman N. Jacobs and William C. Clay.

No. 534. Aerodynamic Characteristics of a Wing with Fowler Flaps, Including Flap Loads Downwash, and Calculated Effect on Take-off, Robert C. Platt.

No. 543. Tank Tests of N.A.C.A. Model 40 Series of Hulls for Small Flying Boats and Amphibians, John B. Parkinson and John R. Dawson.

No. 544. Combustion in a Bomb with a Fuel Injection System, Mildred Cohn and Robert C. Spencer.

No. 546. The Effect of Turbulence on the Drag of Flat Plates, G. B. Schubauer and H. L. Dryden.

Technical Notes:—

No. 546. Comparative Tests of Pitot-Static Tubes, Kenneth G. Merriam and Ellis R. Spaulding.

No. 547. Development of the N.A.C.A. Slot-Lip Aileron, Fred. E. Weick and Joseph A. Shortal.

No. 548. Flight Tests of a Balanced Split Flap with Particular Reference to Rapid Operation, H. A. Soulé.

No. 549. Drag of Prestone and Oil Radiators on the YO-31A Airplane, S. J. De France.

No. 550. Limitations of the Pilot in Applying Forces to Airplane Controls, M. N. Gough and A. P. Beard.

No. 551. Tank Tests of Three Models of Flying Boat Hulls of the Pointed Step Type with Different Angles of Dead Rise, N.A.C.A. Model 35 Series, John R. Dawson.

No. 552. Wind Tunnel Tests of Wing Flaps Suitable for Direct Control of Glide-Path Angle, Fred. E. Weick.

No. 553. Notes on the Technique of Landing Airplanes Equipped with Wing Flaps, Melvin N. Gough.

No. 554. Circular Motion of Bodies of Revolution, Carl Kaplan.

Institute des Recherches de L'Aeronautique, Warsawa, No. 3 (18).

International Aero Press (Technical Bulletin), Nos. 1 and 2, The Hague, Holland.

R. and M. No. 1671. Flexural and Shear Deflections of Metal Spars, I. J. Gerard and H. Boden.

Bulletin of the Institute of Physical and Chemical Research, Tokyo, Volume XV, No. 2.

Scientific Papers of the Institute of Physical and Chemical Research, Volume XXVIII, Nos. 616-621.

Reports of the Aeronautical Research Institute, Tokyo Imperial University. No. 133, Experimentelle Unterschungen uber Augen-Blendung; No. 134, On the Directional Properties of Airscrew Sound, J. Obata, Y. Yosida and U. Yosida.

Journal of the Society of Aeronautical Science of Nippon, Volume III, No. 10, February, 1936.

Noral Handbook, Northern Aluminium Company, Limited.

Aga Course Indicating Airway Beacon.

Gli Scitti Di Leonardo Da Vinci Sul Volo, R. Giacomelli.

Thermodynamics for Engineers, Sir J. A. Ewing (2nd Edition).

Observing the Sun at 19,300 Feet Altitude, Mount Aunconquilcha, Chile, Smithsonian Publication No. 3379.

Royal Commission on the Private Manufacture of the Trading in Arms, Memorandum by the Society of British Aircraft Constructors.

Aeronautical Engineering and Commercial Aviation. A Practical Guide to Your Career. With a Foreword by Capt. G. de Havilland.

Transactions of the American Society of Mechanical Engineers, Volume LVII, 1935.

Proceedings of the Institution of Mechanical Engineers, Volume CXXX, 1935.

Air Mail Operation, Post Office Green Paper No. 23a.

U.S.S.R. in Construction. The Eighteenth Year of the Revolution, Maxim Gorki.

Forthcoming Events

April 1st.—Lecture before the Southampton Branch, by Mr. S. Scott-Hall, M.Sc., A.C.G.I., D.I.C., A.F.R.Ae.S., on "Trans-Atlantic Air Services."

April 2nd.—Lecture before the Wandsworth Technical Institute, by D. Hay Surgeoner, A.F.R.Ae.S., on "The Uses of the Aeroplane."

April 2nd.—Lecture before the Bishop Road Higher Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., A.M.I.Mech.E., on "The History of the Aeroplane."

April 11th.—Lecture before the Isle of Wight Natural History Society, by Mr. T. H. Lloyd, on "A Trip into the Stratosphere."

April 16th.—Lecture before the Bishop Road Higher Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., A.M.I.Mech.E., on "How an Aeroplane is Made."

April 16th.—Lecture before the Coventry Branch, by Mr. J. E. Chorlton, on "Aircraft Instruments."

April 18th.—Visit by the Students' Section to the Royal Aircraft Establishment, South Farnborough. British Subjects only.

April 20th.—Lecture before the Society, by Dr. H. Gough, M.B.E., F.R.S., and Mr. W. A. Wood, on "New Light on the Strength of Materials Afforded by Modern Physics." The lecture will be held at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6.30 p.m. Light refreshments will be served between 6 and 6.25 p.m.

April 21st.—Meeting of Council in the Offices of the Society, 5.30 p.m.

April 23rd.—Lecture before the Manchester Branch, by Flt. Lieut. H. F. Jenkins, on " Training for a Career in Aviation."

April 23rd.—Lecture before the Bishop Road Higher Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., A.M.I.Mech.E., on " How an Aeroplane Flies."

April 28th.—Lecture before the Students' Section, by Mr. J. L. B. Jones, B.Sc., on " The Application of Aeronautical Research to Mechanical Engineering." Dr. G. V. Lachmann, A.F.R.Ae.S., in the chair.

April 30th.—Lecture before the Bishop Road Higher Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., A.M.I.Mech.E., on " The Aeroplane and its Uses."

April 30th.—Lecture before the League of Nations Union on " The Development of Commercial Aviation," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

May 7th.—Lecture before the Bishop Road Higher Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., A.M.I.Mech.E., on " Seaplanes and Flying Boats."

May 10th.—The Royal Aeronautical Society's Garden Party at the Great West Aerodrome.

May 21st.—Wilbur Wright Memorial Lecture and Reception at the Science Museum, South Kensington, " Slippery Surfaces," by Mr. D. R. Pye, M.A., M.I.Mech.E., F.R.Ae.S.

May 26th and 27th.—Associate Fellowship and Associate Membership Examinations in the Offices of the Society.

J. Laurence Pritchard, *Secretary*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

MAY, 1936

Associate Fellowship and Associate Membership Examinations

The Library will be closed on Tuesday and Wednesday, May 26th and 27th, for the Associate Fellowship and Associate Membership Examinations.

Council Meeting

A Meeting of the Council was held in the Offices of the Society on Tuesday, April 21st. The following members were present:—Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair. Captain P. D. Acland, Major T. M. Barlow, Major J. S. Buchanan, Major G. P. Bulman, Mr. H. Roxbee Cox, Mr. A. H. R. Fedden, Mr. A. Gouge, Professor F. T. Hill, Mr. J. E. Hodgson (Honorary Librarian), Major D. H. Kennedy (Honorary Treasurer), Captain A. G. Lamplugh, Mr. W. O. Manning, Mr. F. Handley Page, Dr. N. A. V. Piercy, Lord Sempill, Mr. C. C. Walker, Mr. H. E. Wimperis and Mr. L. A. Wingfield (Solicitor).

Among the business discussed was the following:—Report of the Finance Committee; Report of the Grading Committee; Air House; Report of the Lectures Committee; Report of the Medals and Awards Committee; appointment of representatives on a Joint Committee with the S.B.A.C.; resolutions passed at the Annual General Meeting, 1936; appointment of representatives on other Bodies and appointment of Committees for the year 1936-1937.

Election of Members

The following members were elected at a Meeting of Council held on Tuesday, April 21st, 1936:—

Fellows.—Harold Roxbee Cox, Gustav Victor Lachmann.

Associate Fellows.—Roland Henry Chaplin, Donald McCorquodale, George Wilfrid Mullett, Sigurd Oswald Norman, Robert Randolph Osborn, Reuben Jacob Schmidt, George Sidney Selman, Sidney Youngman Smith, W. Lawrence Tweedie.

Associate Members.—John James Carroll, Thomas Redford Harms, Albert Frederick Johnson, Ernest Arthur Harrop, Walter Lennard Lax, Frederick James Oldland.

Associates.—Anil Chandra Mitter, Robert Perry, William Harold Primrose, Nariman Rustomjee, Gilbert Owen Waters.

Students.—Ronald Geoffrey Anderson, Edward Tranter Barber, Terence David Brian Blake, Maurice Joseph Brennan, Martin Cahill, Patrick Edward Chaundy, Edmund Ray Cooper, John Sterndale Scott Cox, Terence Edward Gouvenot Gardiner, Raymond William Gibbs, Gordon Kenneth Luker Gourlay, Kenneth Alfred John Knell, Roger Ashton Eckford Luard, Peter Gordon Masefield, Claude Reginald Thomas Matthews, Morien Bedford Morgan, Anthony Owen, William Henry Stephens.

Companions.—Marcus Goodall, Alastair Renoldson Ross.

Awards

At a meeting of the Council held on April 21st, 1936, the following awards were made:—

Silver Medal of the Society.

To Mr. B. N. Wallis, for his work on Geodetic Construction.

Simms Gold Medal.

To Mr. W. S. Farren, M.B.E., M.A., M.I.Ae.E., F.R.Ae.S., for his inventions of new methods of the measurement of drag and his designs of scientific apparatus for aeronautical research.

Taylor Gold Medal.

To Mr. E. F. Relf, A.R.C.Sc., F.R.Ae.S., for his paper read before the Society on "The Compressed Air Tunnel."

Sir Charles Wakefield Gold Medal.

To Mr. C. R. Fairey, M.B.E., F.R.Ae.S., for his work on the development of flaps.

Busk Memorial Prize.

To Mr. R. P. Alston, B.A., A.F.R.Ae.S., for his paper read before the Society on "Wing Flaps and Other Devices as Aids to Landing."

Garden Party, May 10th, 1936

On Sunday, May 10th, 1936, the President (Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P.) and the Council will hold a Garden Party at the Great West Aerodrome, near Hayes, the use of which has kindly been given to the Society for the day by the Immediate Past-President, Mr. C. R. Fairey, M.B.E., F.R.Ae.S.

The Garden Party will begin at 2.30 o'clock with a reception by the President and Council, after which members and their guests will have an opportunity of watching a flying display and interesting aircraft. Other arrangements will be announced as they are completed. By permission of the Air Council the Band of H.M. Royal Air Force will play during the afternoon, under the direction of Flight Lieutenant R. P. O'Donnell, M.V.O., Director of Music, R.A.F.

The President and Council extend a special welcome to ladies at the Garden Party.

There will be tea marquees which will provide ample cover and seating for all who come in case the weather is not all it should be.

During the afternoon there will be an exhibition of flying. Among the machines which at present have been arranged for there will be:—Abbott Baynes, Pou-de-Ciel; Abbott Baynes, Auxiliary Sailplane; Blackburn B.2 Trainer (Flying Training, Ltd.); B.A.C. Super Drone; British Aircraft Mfng. Co., Ltd., "Eagle"; British Aircraft Mfng. Co., Ltd., "Swallow"; Cierva Autogiro, "C.30" A, Direct Control; De Havilland "Hornet Moth"; De Havilland "Dragonfly"; Fairey "Battle"; Fairey "Swordfish"; General Aircraft "De Luxe" Monospar; General Aircraft "Ambulance"; General Aircraft "S.T. 18"; International Horseless Carriage Cpn., "Camel"; Light Aircraft Co., Ltd., Aeronca C.3 J.A.P.; Light Aircraft Co., Ltd., Aeronca "Low Wing"; Percival Vega "Gull"; Putnam Aircraft Co., Ltd., Pou-de-Ciel; Miles "Falcon Six"; Miles "Sparrowhawk"; Avro Staggered Cadet; Saro Cloud; Short Scion; Stinson Junior; Tipsy S. Monoplane; Heston Phœnix; Fokker F.36.

Many private owners will be flying over to the Garden Party as well.

During the afternoon there will be an exhibition of towed gliding and manœuvring, a parachute jumping demonstration and an exhibition of fire fighting and rescues by the latest methods.

Last year there were so many applications for tickets at the last minute that it was found impossible to supply them all. It will very greatly help the work of the staff if members will make application as early as possible.

Tickets, including tea, are 5s. each. Applications for tickets must be received by Thursday, May 7th, at the latest.

Wilbur Wright Memorial Lecture and Reception, May 21st, 1936

The 24th Wilbur Wright Memorial Lecture will be delivered by Mr. D. R. Pye, M.A., M.I.Mech.T., F.R.Ae.S., Deputy Director of Scientific Research, Air Ministry, on " Slippery Surfaces," in the Science Museum, by kind permission of the Director, Colonel E. E. B. Mackintosh.

This year is the 70th anniversary of the founding of the Society and arrangements are being made to show, on the night of the lecture, and for a month afterwards, in the Museum, by kind permission of the Director, a special Royal Aeronautical Society's exhibit of aeronautical objets d'art, aeronautical trophies, medals, engravings, etc., and rare or unique articles, as for example, the first aviation passport issued in 1836.

The Council are very anxious to make its exhibit as widely varying and as interesting as possible. Already many offers have been received for the loan of various articles and the Council would welcome the opportunity of obtaining any others on loan. They will all be shown in cases and every care taken of them. Those who have anything of aeronautical interest should write in the first place to the Secretary by May 11th at the latest.

Lecture Suggestions from Members

The Programme of Lectures for the coming Session is now under consideration. The Council would be very glad to receive suggestions for lectures from members immediately in order to help them with their work of providing an interesting series of lectures.

Acknowledgments

The Council acknowledge with grateful thanks the gift of Journals from Mr. Howard Flanders and publications from Miss G. Cottrell. The Council would also like to acknowledge the gift of a number of duplicate copies of N.A.C.A. Reports and Technical Notes from the Air Ministry.

" Worcester " Aviation Scholarships

A member of the Air League of the British Empire has kindly presented a Scholarship of £50 a year for two years to the Thames Nautical Training College, H.M.S. " Worcester," off Greenhithe, Kent, to assist a cadet to become an officer in the Royal Air Force.

The Scholarship will commence at the Michaelmas Term commencing in September, and applications should be forwarded to the Secretary, Ingress Abbey, Greenhithe, Kent, before June 15th, 1936.

Students' Section

The attention of student members is drawn to the visit to the Aerodynamics Department of the National Physical Laboratory on Saturday, July 4th, at 11.0 a.m. Members wishing to participate in this visit should send in their names to the Honorary Secretary of the Students' Section, Mr. H. Leaderman, about a week before that date.

PROGRAMME OF LECTURES.—The programme of meetings of the Students' Section for next Session is now being considered by the Students' Committee. Students who are prepared to read papers should communicate with the Honorary Secretary as soon as possible.

Aviation Service

An Aviation Service will be held in Canterbury Cathedral on Saturday, June 20th, 1936, at 2.50 p.m. The presentation will be made to the Dean and Chapter of a Royal Air Force Ensign and a Civil Air Design. The Archbishop of Canterbury will dedicate the gifts and will address the people.

Those wishing to attend should write before June 1st to the Hon. Festival Manager, Christ Church Gateway, Canterbury.

Additions to the Library

Aerodynamic Theory. Volume VI. Edited by Dr. W. F. Durand.

A Treatise on Screws and Worm Gear, Their Mills and Hobs, by P. Cormac.

The Pilot's Book of Everest, by Squadron Leader Lord Clydesdale and Flight Lieut. D. F. McIntyre.

The B.B.C. Annual, 1936.

Diesel Aircraft Engines, by Paul H. Wilkinson.

Publications Scientifiques et Techniques du Ministere de L'Air. Nos. 77-80.

Junkers and World Aviation, by Captain F. A. Fischer V. Poturzyn.

Some Recent Developments in Internal Combustion Engines, by F. J. Sanger, B.Sc., A.C.G.I., D.I.C., A.F.R.Ae.S.

Stainless Steels, by Dr. W. H. Hatfield, F.R.S.

The Experimental Development of Anchors for Seaplanes, by Wing Commander D. F. Lucking, R.A.F.

Descriptions of Airports and Landing Fields in the United States, U.S. Department of Commerce, Bureau of Air Commerce.

R. & M. No. 1668. Stress-Calculation in Frameworks by the Method of "Systematic Relaxation of Constraints," I, II and III, by R. V. Southwell.

Twenty-First Annual Report of the National Advisory Committee for Aeronautics.

N.A.C.A. Report No. 540. Interference of Wing and Fuselage from Tests of 209 Combinations in the N.A.C.A. Variable-Density Tunnel. Eastman N. Jacobs and Kenneth E. Ward.

Report No. 545. Effects of Air-Fuel Ratio on Fuel Spray and Flame Formation in a Compression-Ignition Engine. A. M. Rothrock and C. D. Waldron.

Report No. 548. Effect of Tip Shape and Dihedral on Lateral-Stability Characteristics. Joseph A. Shortal.

N.A.C.A. Technical Note No. 555. Piloting Technique for Recovery from Spins, by W. H. McAvoy.

Technical Note No. 556. Further Measurements of Normal Accelerations on Racing Airplanes, by N. F. Scudder and H. W. Kirschbaum.

Technical Note No. 557. Considerations of the Take-off Problem, by Edwin P. Hartman.

De Havilland Aircraft, de Havilland Aircraft Company.

Aerodrome and Air Route Lighting Equipment.

Liquid-Propellant Rocket Development. Robert H. Goddard. Smithsonian Publication No. 3381.

Militarwissenschaftliche Mitteilungen.

Technical Publications of the International Tin Research Council, Series A :—

No. 31. The Constitution of the Tin-Rich-Antimony—Tin Alloys, by Prof. D. Hanson and W. T. Pell-Walpole.

No. 32. Influence of Surface Cuprous Oxide Inclusions on the Porosity of Hot-Tinned Coatings on Copper, by W. D. Jones.

No. 33. The Hot-Tinning of Copper: the Attack on the Basis Metal and Its Effects, by E. J. Daniels.

No. 34. Some Recent Investigations on the Corrosion of Tin, by D. J. Macnaughtan and E. S. Hedges.

Report of the Aeronautical Research Institute, Tokyo, No. 135 and 136.

Bulletin of the Institute of Physical and Chemical Research, Japan, Volume XV, Nos. 3 and 4.

Journal of the Society of Aeronautical Science of Nippon, March, 1936.

Chinese Journal of Physics, Volume I, No. 3.

Scientific Papers of the Institute of Physical and Chemical Research, Japan, No. 622-628.

Forthcoming Arrangements

May 5th.—James Forrest Lecture, before the Institution of Civil Engineers, on " Modern Developments in the Design of Aeroplanes," by Mr. E. F. Relf, A.R.C.Sc., F.R.Ae.S.

May 7th.—Lecture before the Bishop Road Higher Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., on " Seaplanes and Flying Boats."

May 10th.—Royal Aeronautical Society's Garden Party at the Great West Aerodrome, Great West Road, by kind permission of Mr. C. R. Fairey. 2.30—7 p.m.

May 12th.—Meeting of Council of the Royal Aeronautical Society.

May 14th.—Lecture before the Bishop Road Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., on " Training R.A.F. Pilots."

May 15th.—International Aero Exhibition in Stockholm, Sweden, May 15th—June 1st, 1936.

May 21st.—Wilbur Wright Memorial Lecture and Reception at the Science Museum, South Kensington. Mr. D. R. Pye, M.A., M.I.Mech.E., F.R.Ae.S., will lecture on " Slippery Surfaces." The Lecture will be followed by a Reception.

May 21st.—Lecture before the Bishop Road Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., on " Imperial Air Routes."

May 21st.—Congress of the Institute of Transport, May 20th—May 23rd.

May 23rd.—Empire Air Day, organised by the Air League of the British Empire.

May 26th.—Lecture before Denmark Hill Toc H, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on " Training Pilots for the Royal Air Force."

May 26th and 27th.—Associate Fellowship and Associate Membership Examinations in the Library of the Society, at 7, Albemarle Street, W.1.

May 28th.—Lecture before the Bishop Road Institute, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., on " A Trip into the Stratosphere."

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

JUNE, 1936

Council Meeting

A Meeting of Council was held on Tuesday, May 12th, 1936, in the Offices of the Society.

Present.—Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair. Captain P. D. Acland, Major G. P. Bulman, Mr. H. Roxbee Cox, Mr. A. H. R. Fedden, Mr. A. Gouge, Professor F. T. Hill, Professor G. T. R. Hill, Captain A. G. Lamplugh, Mr. W. O. Manning, Mr. F. Handley Page, Major R. H. Mayo, Mr. R. J. Mitchell, Dr. N. A. V. Piercy, Professor A. J. Sutton Pippard, Mr. O. E. Simmonds, Mr. C. C. Walker, Mr. L. A. Wingfield (Solicitor).

Among the business under discussion was the following:—Awards by the Amulree Committee, Report of the Finance Committee, Report of the Grading Committee, Election of President 1936-1937, Election of Vice-Presidents 1936-1937, Lecture Dates for the Forthcoming Lecture Session.

Election of President

Mr. H. E. Wimperis, C.B., C.B.E., M.A., M.I.E.E., F.R.Ae.S., Director of Scientific Research at the Air Ministry, was elected President of the Society for the year 1936-1937, at the Council Meeting held on May 12th, 1936. The new President will take office at the first meeting in October.

Election of Vice-Presidents

The following were elected Vice-Presidents of the Society for the year 1936-1937, at the Council Meeting held on May 12th, 1936:—

Major T. M. Barlow, M.Sc. (Eng.), M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.
Mr. F. Handley Page, C.B.E., F.R.Ae.S.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on May 12th, 1936:—

Associate Fellow.—Roy Francis Highett.

Associates.—Erich C. A. Backhaus, Frank E. Buckell, Francis Otto Dorer, Ronald Clifford Hockey, Edward James Kirby, Andrew Auberon Peebles, Geoffrey Temple Perkins.

Students.—Cyril George Buxton, Edward A. George Chlala, Albert R. Crocker, Francis Jeffrey Ireland, Johan Nicolaas Maas, Max Wender, Francis Richard Wilbraham.

Busk Studentship in Aeronautics

A vacancy has arisen for the Busk Studentship in Aeronautics for the year 1936-1937. The Studentship is of the value of about £150, tenable for one year from October 1st. It is open to any man or woman being a British subject and of British descent who has not attained the age of 25 years on October 1st, 1936.

Applications should be made for the necessary forms, which should be returned by June 15th, to Professor B. Melvill Jones, F.R.Ae.S., Engineering Laboratory, Cambridge.

The Armourers and Brasiers Company's Research Fellowship in Aeronautics

The Armourers and Brasiers Company are offering a Research Fellowship in Aeronautics of the value of £300 per annum, commencing on the 1st of October for two years. No age limit is imposed, but preference will be given to candidates under the age of 30 years. The Fellow must have obtained an Honours Degree in Engineering or Physics, or hold some equivalent qualification approved by the Committee.

Applications for the Fellowship should be sent before July 1st to:—The Clerk, The Company of Armourers and Brasiers, 81, Coleman Street, London, E.C.2.

Journals for 1936

The Council would be very grateful if members who have finished with their January and February Journals for 1936, and who do not wish to keep them to complete their volume, would kindly return them to the Society. There is a shortage of these numbers owing to the increased demand from outside subscribers. This is one of the ways in which members can help the Society financially as it enables Journal subscriptions to be accepted for the whole year, which would otherwise not be possible.

Awards

At a meeting of the Amulree Committee held on April 27th, 1936, the following awards were made on the recommendation of the Council of the Royal Aeronautical Society:—

British Gold Medal for Aeronautics.

Dr. Hugo Eckener for his technical achievements in lighter-than-air craft.

British Silver Medal for Aeronautics.

Mr. A. J. Rowledge, M.I.A.E., F.R.Ae.S., for his scientific achievements in the development of aircraft engines.

Schools Lectures

The Secretary would be glad to hear from members of the Society wishing to give lectures to their old schools or to schools in their particular neighbourhood. Lecture notes and slides will be supplied from the Office providing sufficient notice is given. As the demand for these lectures is increasing, members are asked to inform the Secretary as soon as possible as to the lecture required, date of lecture, and the name of the school.

Library Closing

The Library will be closed on Saturday afternoons from Saturday, June 27th, until Saturday, September 19th, both inclusive. Members are reminded that books will be sent on loan through the post on application to the Office. Members pay postage both ways.

Out-of-Print Publications

The Secretary has had several enquiries for the following publication. If any member has a copy for disposal will they kindly let the Secretary know. "A

Glossary of Aeronautical Terms," translated and adapted to the French by Leonard F. Plugge, 1921. Published by His Majesty's Stationery Office.

Additions to the Library

The following books have been added to the Library during the month:—

Lynx IV* Aero Engine (with Appendices on the Lynx IV (Mod.) and Lynx IV Engines). Air Publication, No. 1287, Volume I.

Official Bulletin, No. 23, of the International Commission for Air Navigation, December, 1935.

A Manual of Modern Navigation, by S. M. Burton.

Technical Publications of the International Tin Research and Development Council, Series A:—

No. 35. Research on Thin Layers of Tin and Other Metals. II. The Corrosion of Metals by Technical Insulating Oils, by F. J. Haringhuizen and D. A. Was.

No. 36. Factors Influencing the Rate of Attack of Mild Steels by Typical Weak Acid Media, by T. P. Hoar and D. Havenhand.

No. 37. Methods of De-tinning Tin Plate for Examination of the Thickness and Continuity of the Alloy Layer, by A. W. Hothersall and W. N. Bradshaw.

No. 38. A Study of the Origin of Porosity in the Tin Coating of Tin Plate, by A. W. Hothersall and J. C. Prytherch.

Chinese Journal of Physics, Volume I, No. 3.

Ballonsport in 1935, Nederlandse Ballonsport-Vereniging.

Elements of Diesel Engineering, Orville Adams.

Maintenance of High Speed Diesel Engines, A. W. Judge.

Engineering Abstracts, No. 67. April, 1936. Institution of Civil Engineers.

Modern Developments in the Design of Aeroplanes, E. F. Relf (Institution of Civil Engineers).

Dowty Aircraft Components.

Report of the National Physical Laboratory for the Year 1935.

A View on the Thurston Rotor Cowl for Air-Cooled Engines, by G. Otten.

Eighteenth Annual Report of the National Research Council of Canada, 1934-1935.

Report of the Aeronautical Research Institute, Tokyo Imperial University, No. 137, March, 1936.

R. & M. No. 1678. Laminar Boundary Layer on the Surface of a Sphere in a Uniform Stream, S. Tomotika.

Resumen de las Observaciones Aerologicas, 1935.

Bulletin of the Institute of Physical and Chemical Research, Volume XV, No. 5.

Scientific Papers of the Institute of Physical and Chemical Research, Nos. 629-631.

Science Reports of the Tokyo Bunrika Daigaku, Nos. 50-51.

The Carnegie United Kingdom Trust, Twenty-second Annual Report for the Year ending December 31st, 1935.

Scientific Notes of the India Meteorological Department, Volume VI, No. 67. Measurement of Vertical Currents in the Atmosphere, Mainly of Thermal Origin, with Pilot Balloons, by K. R. Ramanathan and K. P. Ramakrishnan.

Handbook of the Collections Illustrating the Propulsion of Aircraft, Science Museum, South Kensington. 2nd Edition.

Annual Report of the World Power Conference, 1935.

Svenska Teknologfoeningen, Ledamotsforteckning, March, 1936.

Hispano-Suiza, Les Usines.

Swedish Air Pilot, 1936.

Publications of the Laboratorio di Aeronautica della R. Scuola di Ingegneria Di Torino:—

No. 75. La Torsione dei Solidi Cilindrici a Sezione Allungata, Ing. Placido Cicala.

No. 76. Atterramento Con Ipersostentatori, Professor M. Panetti.

No. 77. Le Azioni Aerodinamiche Sui Profili Di La Oscillanti in Presenza Di Corrente Uniforme, Ing. Placido Cicala.

No. 78. Trasmettitori Idraulici, Ing. Paola Aymerito.

No. 79. Ammortizzatori Idraulici Impiegati Nei Carrelli Degli Aeroplani, Ing. Paolo Aymerito.

No. 80. La Teoria Della Turbulenza Ed El Trasporto Della Quantita Di Moto El Della Vorticita, C. Ferrari.

No. 81. Rendiconti Sperimentali Del Laboratorio Di Aeronautica Del Regio Instituto Superiore di Ingegneria di Torino, 2nd Serie.

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

JULY, 1936

HONOURS.

The following honour was announced in the Birthday Honours' List:—

Royal Victorian Order.

G.C.V.O.—Viscount Charles C. Wakefield, C.B.E.

Viscount Wakefield is an Honorary Fellow of the Society.

AUGUST BANK HOLIDAY.

The Offices of the Society will be closed from Saturday, August 1st, to Monday, August 3rd, inclusive.

COUNCIL MEETING.

A Meeting of the Council was held on Tuesday, June 9th, 1936, in the Offices of the Society.

Present.—Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair. Captain P. D. Acland, Major J. S. Buchanan, Major G. P. Bulman, Mr. H. Roxbee Cox, Mr. A. H. R. Fedden, Professor F. T. Hill, Professor G. T. R. Hill, Major D. H. Kennedy (Honorary Treasurer), Mr. W. O. Manning, Major R. H. Mayo, Mr. F. Handley Page, Dr. N. A. V. Piercy, Professor A. J. Sutton Pippard, Mr. H. E. Wimperis, Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—Lectures for the forthcoming Session; Report of the Finance Committee; Report of the Grading Committee; Wilbur Wright Memorial Lecture and Reception.

LIBRARY CLOSING.

The Library will be closed on Saturday afternoons from Saturday, June 27th, until Saturday, September 19th, both inclusive. Members are reminded that books will be sent on loan through the post on application to the Office. Members pay postage both ways.

ELECTIONS.

The following recommendations of the Grading Committee were approved by the Council at their meeting on June 9th, 1936:—

Member.—Alfred Charles Morris Jackaman.

Associate Fellows.—Christopher Ainsworth Davis, Frederic Wyndham Freke Hewitt, Clifford Hirst Jackson, Paul Goudime-Levkovitsch.

Associate Members.—James John Brand, Richard Ernest Drake, George Humphrey Winn.

Associates.—Shiu Parkash Kathuria, John Grimmond Gunn.

Students.—Harry Edward Adams, Peter Alan Lantsbery Grear, James Joseph Browne Houston, Robert Miller, Stanley Robert Parker, Douglas Carl Stewart, Mervyn Millington Waghorn, George Herbert Westlake, John Rayner White.

Companions.—D. J. L. Cowan, George Fred Parkhurst Trubridge.

ACKNOWLEDGMENTS.

The Council gratefully acknowledge the return of Journals from the following members of the Society in response to an appeal made in the June issue of the Journal:—Miss L. Chitty (Fellow), Mr. A. E. Woodward Nutt (Associate Fellow), Mr. E. F. Relf (Fellow), Mr. F. P. Walsh (Associate Fellow) and Colonel L. M. Wilson (Associate).

ASSOCIATE FELLOWSHIP AND ASSOCIATE MEMBERSHIP EXAMINATIONS.

The following Candidates were successful at the examinations held in May, 1936:—

ASSOCIATE FELLOWSHIP.

L. G. Byrne	Applied Mathematics.
W. E. Crook	Applied Mathematics.
R. M. Helsdon ...	Aerodynamics. Design (Aircraft).
F. J. Horn	Strength of Aeronautical Materials and Structures. Aerodynamics.
D. Milne	Pure Mathematics.
L. W. Nethercott ...	Aircraft Materials.
A. D. W. Pimm ...	Strength of Aeronautical Materials and Structures. Aerodynamics.
E. J. C. Rayner ...	Pure Mathematics.
G. J. Thomson ...	Aerodynamics. Design (Aircraft).

ASSOCIATE MEMBERSHIP.

C. R. P. Bizeray ...	Pure Mathematics.
P. H. Campion ...	Applied Mathematics.
L. D. V. Edwards ...	Pure Mathematics. Aerodynamics.
R. Lindsay-Smyth ...	Theory of Internal Combustion Engines.
R. C. Morgan ...	Air Transport.
M. K. Tha	Aircraft Materials.
H. G. Winton ...	Applied Mathematics. Strength of Aeronautical Materials and Structures. Theory of Internal Combustion Engines.

ADDITIONS TO THE LIBRARY.

Report of the Advisory Council of the Science Museum for the Year 1935.

International Organisation in European Air Transport, by Laurence C. Toms and J. P. Chamberlain.

Minutes of Proceedings of the Institution of Civil Engineers, Volume 239, May, 1936.

Prevision du Temps par L'Analyse des Cartes Meteorologiques, by Jacques Van Meighem.

The Aircraft Year Book for 1936.

Combustion-Chamber Design for Oil Engines, by Paul Belyavin.

From Box-Kites to Bombers, by George Fyfe.

Airport Management, by Major L. F. Richard.

R. & M. No. 1680 (Abstract). On the Synthesis and Analysis of Simple-Stiff Frameworks, by H. Roxbee Cox.

Bibliography of Aeronautics, 1932. N.A.C.A.

Reports of the National Advisory Committee for Aeronautics:—

No. 541. Aerodynamic Characteristics of Wings with Cambered External-Airfoil Flaps, Including Lateral Control with a Full-Span Flap, by Robert C. Platt.

No. 542. Potential Flow About Arbitrary Biplane Wing Sections, by I.E. Garrick.

No. 547. Wind-Tunnel Interference with Particular Reference to Off-Center Positions of the Wing and to the Downwash at the Tail, by Abe Silvertein and James A. White.

No. 549. Wind-Tunnel Investigation of the Aerodynamic Balancing of Upper-Surface Ailerons and Split Flaps, by Carl J. Wenzinger.

No. 551. Aircraft Compass Characteristics, by John B. Petersen and Clyde W. Smith.

No. 550. Cooling Characteristics of a Two-Row Radial Engine, by Oscar W. Schey and Vern G. Rollin.

Technical Notes of the National Advisory Committee for Aeronautics:—

No. 560. A Comparison of Corrosion-Resistant Steel (18 per cent. Chromium—8 per cent. Nickel) and Aluminium Alloy (24 St.), by J. E. Sullivan.

No. 558. The Performance of a De Palma Roots-Type Supercharger, by Oscar W. Schey and Herman H. Ellerbrock, Jr.

No. 559. Combustion-Engine Temperatures by the Sodium Line-Reversal Method, Maurice J. Brevoort.

Report of the Aeronautical Research Institute, Tokyo, No. 138, April, 1936.

Properties of Aluminium Sheet, by Sadao Horiguchi.

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

AUGUST, 1936

August Bank Holiday

The Offices of the Society will be closed from Saturday, August 1st, to Monday, August 3rd, inclusive.

Associate Fellowship and Associate Membership Examinations

The next examinations will be held in December, 1936. Intending candidates must send in their entry forms on or before September 30th, 1936.

Acknowledgments

The Council gratefully acknowledge the receipt of One Guinea as a donation to the Endowment Fund from Mr. J. W. C. Logan. Mr. Logan has contributed to this Fund regularly for the past few years, and the Council would specially like to thank him for his continued generosity.

The Council would also like to acknowledge the receipt of £1 1s. 0d. to the Fund from Mr. J. D. L. Stratton, a Student of the Society, who is serving abroad with the Royal Air Force.

Elliott Memorial Prize

The Elliott Memorial Prize has been awarded to Sergeant Apprentice Willis, of Halton.

Schools Lectures

The Council hope that any members who have an opportunity of delivering one of the following lectures to Schools will write to the Secretary. The lectures are complete in themselves and are illustrated with 40–50 slides.

1. The History of the Aeroplane.
2. The Aeroplane and its Uses.
3. Flying Boats and Seaplanes.
4. Training R.A.F. Pilots.
5. How an Aeroplane is Made and Flies.
6. A Trip into the Stratosphere.
7. How an Aeroplane Flies.
8. How an Aeroplane is Made.

Additions to the Library

Azimuth Tables, by John Burdwood.
Proceedings of the Institution of Mechanical Engineers, Volume 131, 1935.
Small Two-Stroke Aero Engines, C. F. Gaunter.
Flugzeug-Typenbuch, Dipl. Ing. Helmut Schneider.
Pacific Islands Year-Book, 1935-1936.
Carbon and Alloy Steels, Thos. Firth and John Brown Limited.

Tool and Die Steels, Thos. Firth and John Brown Limited.
Hardening of Tool and Die Steels, Thos. Firth and John Brown Limited.
Aluminium Tubes and Pipes, British Aluminium Company Limited.
Points on Piston Rings, Wellworthy Piston Rings Limited.
Decade of Progress in Civil Aeronautics Shown in Statistics, Air Commerce Bulletin, Volume 7, No. 12.

Reports & Memoranda of the Aeronautical Research Committee:—

No. 1675. Graphical Method of Calculating Performance of Airscrew, C. N. H. Lock.
No. 1677. Flight Tests on an Atlas Fitted with Autoslots having Various Link Arrangements, W. G. Jennings.
No. 1694. A Routine Method of Stressing for Three-Ply Covered Fuselages, with Special Reference to Some Mechanical Tests on a Particular Fuselage, H. Davis.
No. 1695. Effect of Static Pressure Along the Axis of an Open-Jet Tunnel of (a) Nozzle Flare and (b) A Ring in the Collector, F. B. Bradfield and G. F. Midwood.

Technical Reports of the National Advisory Committee for Aeronautics:—

No. 552. Wind-Tunnel Tests of 10-Foot-Diameter Autogiro Rotors, John B. Wheatley and Carlton Bioletti.
No. 553. Some Effects of Argon and Helium Upon Explosions of Carbon Monoxide and Oxygen, Ernest F. Fiock and Carl H. Roeder.
No. 554. Wind-Tunnel Investigation of Ordinary and Split Flaps on Airfoils of Different Profile, Carl J. Wenzinger.
No. 555. Air Flow Around Finned Cylinders, M. J. Brevoort and Vern G. Rollin.
No. 556. Further Studies of Flame Movement and Pressure Development in an Engine-Cylinder, Charles F. Marvin, Jnr., Armistead Wharton and Carl H. Roeder.

Technical Notes of the National Advisory Committee for Aeronautics:—

No. 561. Full-Scale Wind-Tunnel Tests to Determine a Satisfactory Location for a Service Pitot-Static Tube on a Low-Wing Monoplane, John F. Parsons.
No. 562. Remarks on the Elastic Axis of Shell Wings, Paul Kuhn.

J. LAURENCE PRITCHARD, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES
SEPTEMBER, 1936

LECTURE PROGRAMME, 1936-1937.

The following lectures have been arranged for the 1936-1937 Session. The lectures will be held at 6.30 p.m. in the Lecture Hall of the *Royal Society of Arts, 18, John Street, Adelphi, W.C.2.* Refreshments will be provided free of charge between 6 and 6.30 p.m.

1936.

October 8th.—" Aerodynamic and Structural Features of Tapered Wings." Dr. G. V. Lachmann, F.R.Ae.S.

October 22nd.—" The Economics of Air Line Operation." Mr. L. T. H. Greig.

November 12th.—" The Part Played by Skin Friction in Aeronautics." Dr. F. W. Lanchester, F.R.S., Hon. F.R.Ae.S., M.Inst.C.E., M.I.Mech.E., M.I.A.E.

November 19th.—" Aerodrome Design." Mr. Nigel Norman, F.R.Ae.S.

December 10th.—" Civil Flying Boats." Mr. A. Gouge, B.Sc., F.R.Ae.S.

December 17th.—Title to be announced later. Professor B. Melvill Jones, A.F.C., M.A., F.R.Ae.S.

1937.

January 14th.—" Magnesium Alloys." Dr. C. H. Desch.

January 28th.—" Plastic Materials for Aircraft Construction." Dr. N. A. de Bruyne.

February 11th.—" The Automatic Pilot." Mr. F. W. Meredith, B.A., and Mr. P. A. Cooke, O.B.E., M.C.

February 18th.—" Compression Ignition Engines for Aircraft." Mr. A. H. R. Fedden, M.B.E., M.I.A.E., M.S.A.E., F.R.Ae.S.

February 25th.—" Power Measurements in the Air." Mr. N. S. Muir, B.Sc., A.M.I.Mech.E.

March 11th.—" Airscrew Blade Vibration." Major B. C. Carter, A.R.C.Sc., D.I.C., M.I.Mech.E., F.R.Ae.S.

April 8th.—" Control Problems." Mr. A. G. Pugsley, M.Sc., A.M.I.Struct.E.

April 22nd.—" American Engine Development." Mr. G. J. Mead, A.F.R.Ae.S.

May. —.—Wilbur Wright Lecture, " Turbulence." Dr. Theodor von Kármán, F.I.Ae.S.

LIBRARY.

Members are reminded that the Library will be re-opened on Saturday afternoons on and from September 26th. The hours for opening are 9.30—5 p.m. weekdays and 9.30 to 12.30 and 2—5 p.m. on Saturdays.

ASSOCIATE FELLOWSHIP AND ASSOCIATE MEMBERSHIP EXAMINATIONS.

The next Associate Fellowship and Associate Membership Examinations will be held at 7, Albemarle Street, W.1, in December, 1936. The exact date will be announced as soon as possible. Candidates should send in their entries before September 30th, 1936.

JOURNALS WANTED.

The Secretary is particularly anxious to obtain copies of the following Journals and Report of the Society:—

April, 1897.
January, 1899.
2nd Annual Report of the Society—1867.

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

The attention of members is drawn to the Second International Congress of the International Association for Testing Materials, which will be held in London from April 19th—24th, 1937. All particulars regarding membership, papers to be read, fees, etc., may be obtained from the Honorary Secretary of the Congress, Mr. K. Headlam-Morley, 88, Victoria Street, W.1.

ACKNOWLEDGMENTS.

The Council acknowledge with thanks the following:—A copy of the First Annual Report of the Society from Mrs. F. H. Wenham; Negatives from Mr. H. Willis (Companion); Catalogue of British Scientific and Technical Books, 1930, from Lieut.-Col. M. O'Gorman (Fellow).

ADDITIONS TO THE LIBRARY.

The following books have been added to the Library during the month:—

Publications Scientifique et Technique du Ministere de l'Air.
No. 87. Recherches sur l'Influence de l'Angle D'Ouverture D'un Ajutage Divergent, Jean Demontis.
No. 88. Enduits Cellulosiques Pour Toile D'Avions, Jean Grard.
No. 89. Étude du Système Antimoine-Étain-Zinc et Contribution a l'Étude des Antifrictions a Base de Zinc, Robert Blondel.
No. 90. Électromètre Plan-Sphère a Suspension Bifilaire, Fernand Charron.
No. 91. Étude de la Susceptibilité Corrosive des Métaux. Par la Méthode Coloriscopique et par la Méthode des Éprouvettes Minces, Marcel Prot et Mlle. N. Goldowski.
Exploring the Stratosphere, Gerald Heard.
The Boy's Romance of Aviation, Captain A. O. Pollard, V.C., M.C., D.C.M.
Guide for Flying Instructors, Guild of Air Pilots and Air Navigators of the British Empire.
The Airplane and its Engine (3rd Edition), C. H. Chatfield, C. Fayette Taylor and Shatswell Ober.
Theory of Elasticity, S. Timoshenko.
Strength of Materials (Fourth Edition), James E. Boyd.
The Distortion of Metal Crystals, C. F. Elam.
Non-Corrodible Aircraft Steels, Firth-Vickers Stainless Steels, Limited.
Annual Report of the National Central Library, 1935-1936.
Le Vol des Insectes, Docteur A. Magnan.
The New Model Aeroplane Manual, L. H. Sparey and C. A. Rippon.
The Book of Famous Flyers, J. Mollison.
Air Navigation Directions (A.N.D. 13), 1936.
Design Requirements for Aeroplanes for the Royal Air Force. (A.P. 970.)
Air Estimates, 1935, with Supplement for 1936.
Résumé of Commercial Information. Special Issue No. 4, 1936. Number of Registered Civil Aircraft.
Practical Aircraft Stress Analysis, D. R. Adams.
Manual of Meteorology, Sir Napier Shaw.
R. & M. No. 1693. Air and Vapour Locks in Fuel Systems, M. A. A. Allfrey.

J. LAURENCE PRITCHARD, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

OCTOBER, 1936

CORONATION GARDEN PARTY, 1937.

The Coronation Garden Party will be held on Sunday, May 9th, 1937, by kind permission of Mr. C. R. Fairey, M.B.E., F.R.Ae.S., at the Great West Aerodrome, near Hayes, Middlesex

INAUGURAL LECTURE.

The Inaugural Lecture of the 1936-37 Session will be held on Thursday, October 8th, 1936, at 6.30 p.m., when Dr. G. V. Lachmann, F.R.Ae.S., will lecture on "Aerodynamic and Structural Features of Tapered Wings." The lecture will be held in the Lecture Theatre of the *Royal Society of Arts*, 18, *John Street, Adelphi, W.C.2.* Light refreshments will be served from 6—6.25 p.m. to members free of charge. Visitors will only be admitted by ticket obtainable through a member of the Society.

COUNCIL MEETING.

At a meeting of Council held on September 15th, 1936, the following members were elected:—

Fellow.—Harold James Penrose (from Associate Fellow).

Associate Fellows.—Wilfrid Evelyn Crook, Maurice Herrod-Hempsall (from Student), Harold Nichols Horne, Hugh Stuart Howat, Reginald Leach, Geoffrey Alexander McMillan (from Student), Glencairn Sholto Ogilvie (from Student), H.R.H. Prince Alvaro de Orleans-Borbon, Alexander Robert Wright (from Companion), Stephen Joseph Zand.

Associate Members.—George Carter, Edward Wood Dodds, John Butler Harris, Charles Idrys Kidston, Albert Henry Lawrence, Robert Charles Morgan (from Associate), Harold Parkinson (from Associate), Harold George Winton.

Associates.—Sydney Arthur Claude Baker, Graves Patrick Maxwell Eves, Henry Arthur Fowler-Tutt, Sydney Charles Hart-Still, Edward Lumley Delpratt White, George Humphrey Winn.

Students.—Leslie Richard Eyre Appleton, Philip Alfred Barber, Peter Charles Bromwich, Ralph Cuthbert Chisholm Brown, William Allison Hall Brown, Thomas Ignatius Burke, Walter Graham Clark, Donald Diamond, Denis Pierpoint Edkins, Thomas Anthony Gawade, Arnold Alexander Hall, Frazer Apsley Harte, Harold Henry Hopkins, Norman Hugh John Johnson, James William Kenny, John William Kirby, Cameron Frederick Mervyn-Jones, Terence Macrae Myles, Lyman Manary Nesbitt, Peter Alfred Henry Pooley, Roger Roach, John Edmund Roe, Norman Sandham, Sheldon Benton Smith, Ralph Francis Newman Swingler, Anant Vishnu Vartak, William Alfred Canning Weetman, Allen Craig Williams.

Companions.—Paul Howlett Campion, Hugh Stanley Ellis (from Student), James Hunter Farr, Arthur Drummond Williams Pimm, Patrick Ryan, Peter Shaw, Kwei-Jui Tai.

Among the business discussed was the following:—Reports of the Finance Committee; Report of the Grading Committee; Programme of Functions for 1937, including the Wilbur Wright Memorial Lecture; Appointment of a Representative to the Fiftieth Anniversary Meeting in Montreal next June of the Engineering Institute of Canada; Appointment of Referees for the R.38 Memorial Prize Paper; Dinner in honour of Major Lester Gardner during his visit at the end of October; Formation of a Branch of the Society in India; Gift from Mr. Griffith Brewer of a bronze bust of Wilbur Wright.

Major Lester Gardner.

Major Lester Gardner, the Secretary of the Institute of Aeronautical Sciences, will be visiting London on October 28-30. He will be at the Royal Aero Club the greater part of Wednesday, October 28th, and hopes that any friends who wish to see him will meet him there on that day. A dinner is being arranged to Major Gardner during his visit.

Associate Fellowship and Associate Membership Examinations.

The next Associate Fellowship and Associate Membership Examinations will be held in the Offices of the Society on Tuesday, December 15th, and Wednesday, December 16th, 1936.

The Library will be closed on both these days.

Change of Notation in the Society's Examinations.

The Society has decided to change the definitions and notations of the aerodynamic coefficients used in its examination papers. The new coefficients, as recommended by the Aeronautical Research Committee, will be defined in terms of the dynamic pressure of a fluid, following American and Continental practice. Thus the non-dimensional lift coefficient will be denoted to C_L and will be given by the relation $C_L = L/\frac{1}{2}\rho V^2 S$.

Similarly for C_D, C_m, etc., the new coefficients being double the K_L, K_D, K_m, etc., coefficients employed hitherto. Full definitions will, however, be given in the forthcoming examination papers until candidates have become familiar with the new notation.

Acknowledgments.

The Council acknowledge with grateful thanks the gift of £25 from an anonymous member to pay the donation of that amount which the Society has made towards the cost of the Second International Congress of the International Association for Testing Materials to be held in London in April, 1937.

The Council also gratefully acknowledge the donation of five shillings to the Endowment Fund from Flight Sergeant O. S. J. Burrows, Associate; the gift of Journals from Mr. T. B. Ringwood, Associate Member; the gift of an extract from *L'Aerophile* of March 15th, 1909, from Mr. H. R. Gillman, Associate Fellow; and the gift of manuscript of some work by Mr. William Quartermain from Mr. John Rennie.

Brancker Memorial Lecture.

The Second Brancker Memorial Lecture, under the auspices of the Institute of Transport, will be held on Monday, November 23rd, 1936, at 6 p.m., at the Institution of Electrical Engineers, Victoria Embankment, W.C.2. The lecture will be delivered by Mr. D. H. Handover, M.Inst.T., Traffic Manager, Imperial Airways, Limited, and the subject will be "Some Aspects of the Organisation of the Empire's Airways."

The Institute of Transport has extended a cordial invitation to members of this Society to attend the lecture.

LIBRARY.

The Library has been re-opened on Saturday afternoons from September 26th. The hours for opening are 9.30—5 p.m. on weekdays and 9.30—12.30 and 2—5 p.m. on Saturdays.

ADDITIONS TO THE LIBRARY.

Radio Operating Questions and Answers, A. R. Nilson and J. L. Hornung.

Rigging and Airframes, J. Campbell Corlett.

Flight To-day, J. L. Nayler and E. Ower.

Concrete in Aerodrome Construction, The Cement and Concrete Association.

Abridgments of Patent Specifications, Numbers 420,001-440,000.

Aero Engines. Inspection of, During Manufacture, Overhaul and Test ("D" Licence), A. N. Barrett. (4th Edition.)

International Index to Aeronautical Technical Reports, 1935.

Stainless Steels, Dr. W. H. Hatfield, F.R.S.

Heat-, Rust- and Acid-Resisting Steels, Dr. W. H. Hatfield.

Classification for Works on Pure and Applied Science in the Science Museum Library.

Smithsonian Miscellaneous Collection, Volume 95, Number 15. Further Evidence on the Dependence of Terrestrial Temperatures on the Variations of Solar Radiation, by C. G. Abbot.

Meteorological Office, Professional Notes, No. 72. Upper Winds at Wadi Halfa (Sudan), by J. Durward.

Report on the Progress of Civil Aviation, 1935.

Bird Flight—200 Action Photographs, Gordon Aymar.

Reports and Memoranda of the Aeronautical Research Committee:—

No. 1682. Effect of Weight on Take-off and Landing, E. Finn and S. P. Osborne.

No. 1687. Performance and Longitudinal Stability of a Single-Engined High Wing Monoplane. (Experiments on a Quarter-Scale Model with Airscrew Running.) L. W. Bryant, D. H. Williams and A. F. Brown.

No. 1688. Measurement of Profile Drag by the Pitot-Traverse Method, by the Cambridge University Aeronautics Laboratory.

No. 1689. Contribution of Body and Tail of an Aeroplane to the Yawing Moment in a Spin. H. B. Irving, A. S. Batson and J. H. Warsap.

No. 1690. Stressing of Aeroplane Wings due to Symmetrical Gusts, L. W. Bryant and I. M. W. Jones.

No. 1692. Rolling up of the Surface of Discontinuity Behind an Aerofoil of Finite Span, F. L. Westwater.

No. 1696. Heat Dissipation of Ethylene Glycol Radiators and Comparison with Water Radiators. C. Anderton Brown and F. G. Barlow.

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

The attention of members is drawn to the Second International Congress of the International Association for Testing Materials, which will be held in London from April 19th-24th, 1937. All particulars regarding membership, papers to be read, fees, etc., may be obtained from the Honorary Secretary of the Congress, Mr. K. Headlam-Morley, 28, Victoria Street, London, S.W.1.

PUBLICATIONS WANTED.

The Secretary is particularly anxious to obtain copies of the following publications:—

Journal of the Society for April, 1897, and January, 1899.
Second Annual Report of the Society, 1867.
A Glossary of Aeronautical Terms, Translated and Adapted to the French by Leonard F. Plugge.

FORTHCOMING EVENTS.

October 1st.—Annual General Meeting of the Students' Section in the Library of the Society at 7 p.m.

October 8th.—Lecture before the Society by Dr. G. V. Lachmann, F.R.Ae.S., on "Aerodynamic and Structural Features of Tapered Wings," at 6.30 p.m., in the Lecture Theatre of the *Royal Society of Arts*, 18, *John Street, Adelphi, W.C.2.*

October 15th.—Lecture before the Students' Section in the Library of the Society, at 7, Albemarle Street, London, W.1, at 7 p.m., by E. F. Relf, Esq., F.R.Ae.S., on "Recent Developments in Aeronautical Research." Chairman: Mr. H. T. Tizard, C.B., A.F.C., F.R.S., F.R.Ae.S.

October 15th.—Lecture before the Coventry Branch, by S. Barraclough, on "Diamet Inspected Steels."

October 16th.—Lecture before West Hartlepool Technical College, by J. Bell, Esq., A.R.Ae.S.I., on "Recent Progress in Aviation."

October 17th.—Visit of the Students' Section to Messrs. Short Brothers, Limited, Rochester, at 10 a.m., and to Messrs. Pobjoy Airmotors and Aircraft, Limited, Rochester, at 3 p.m.

October 18th.—Lecture before St. Edward's School, Oxford, by A. F. Houlberg, Esq., A.M.I.Ae.E., on "The History of the Aeroplane."

October 19th.—Lecture before the King's School, Ely, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "Seaplanes and Flying Boats."

October 22nd.—Lecture before the Society by L. T. H. Greig, Esq., on "The Economics of Air Line Operation," at 6.30 p.m., in the Lecture Theatre of the *Royal Society of Arts*, 18, *John Street, Adelphi, W.C.2.*

October 23rd.—Lecture at Bethnal Green, by A. G. H. Diamond, Esq., A.R.Ae.S.I., on "The Uses of the Aeroplane."

October 23rd.—Lecture before Rutherford College, by J. Bell, Esq., A.R.Ae.S.I., on "How an Aeroplane is Made and Flies."

October 28th.—Major Lester Gardner, of the Institute of Aeronautical Sciences, will be "At Home" at the Royal Aero Club to all friends.

November 3rd.—Lecture before Students' Section in the Library of the Society, at 7 p.m., by Mr. J. V. Connolly, B.E., A.F.R.Ae.S., on "Technical Aeronautics in Australia." Chairman: Mr. Thurstan James.

November 7th.—Visit of Students' Section to De Havilland Aircraft Company, Limited, Stag Lane Works, Edgware, at 3 p.m.

November 7th.—Lecture before Brighton College, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "A Trip into the Stratosphere."

November 12th.—Lecture before Society by Dr. F. W. Lanchester, F.R.S., Hon. F.R.Ae.S., M.I.Mech.E., F.R.A.S., on "The Part Played by Skin Friction in Aeronautics," at 6.30 p.m., in the Lecture Theatre of the *Royal Society of Arts*, 18, *John Street, Adelphi, W.C.2.*

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES
NOVEMBER, 1936

Council Meeting.

A Meeting of the Council was held in the Offices of the Society on Tuesday, October 20th, 1936.

Present.—Mr. H. E. Wimperis (President) in the chair; Major J. S. Buchanan, Mr. H. Roxbee Cox, Mr. A. H. R. Fedden, Mr. A. Gouge, Professor F. T. Hill, Professor G. T. R. Hill, Major D. H. Kennedy (Honorary Treasurer), Capt. A. G. Lamplugh, Mr. W. O. Manning, Mr R. J. Mitchell, Mr. F. Handley Page (Vice-President), Dr. N. A. V. Piercy, Professor A. J. Sutton Pippard, Mr. C. C. Walker, and Mr. O. E. Simmonds

Among the business discussed was the following:—Cablegram to Miss J. Batten; letters of congratulation to the Bristol Aeroplane Company and the Royal Aircraft Establishment; Fiftieth Anniversary of the Engineering Institute of Canada; Election of Lieut.-Colonel J. T. C. Moore-Brabazon to the Council; Report of the Finance Committee; Report of the Grading Committee; proposed alterations to Rules to include a Graduate Grade of membership; proposed alteration of Rule dealing with the scrutinising and counting of votes at the Annual General Meeting; organisation of discussions following the Society's lectures.

Elections.

The following members were elected at the Meeting of Council held on October 20th, 1936:—

Fellows.—A. C. Kermode (from Associate Fellow).

Associate Fellows.—Robert Graham, E. T. Jones, P. McCormack, R. A. Shaw, A. J. Sidery, J. B. Taylor, J. I. Waddington, J. L. Watkins, D. B. Winter.

Associate Member.—R. Glynn Jones.

Associates.—C. G. K. Browne, E. W. La Borde, J. H. Millar, R. D. Stoner.

Students.—D. Cameron, A. V. Cleaver, H. Davies, D. R. H. Dickinson, L. T. B. Fenn, D. F. Fletcher, G. R. Forbes, W. A. Fowler, J. Halliwell, D. A. C. Harper, R. G. S. Hogarth, E. T. House, D. I. Husk, K. Kenney, A. V. Kilburn, Miss Sheila McGuffie, B.Sc., W. J. M. Moss, E. R. Owen, E. G. Pattison, G. A. A. Russell, C. H. Sworder, D. M. Ware, C. A. Wood-Collins.

Companions.—A. Gibbons, Harold Zettersten.

Dinners After Lectures.

As in previous years, the Royal Aero Club are arranging a late dinner for those who attend lectures of the Society. These dinners have been fixed at 2s. 6d. and members of the Society will be made honorary members of the Royal Aero Club for those evenings. It is hoped that as many members of the Society as possible will take advantage of the facilities offered by the Royal Aero Club, whose address is 119, Piccadilly, W.1. Telephone: Grosvenor 1246-7-8.

Paris Aero Show.

The 15th Exposition Internationale de l'Aeronautique will be held in the Grand Palais, Paris, from November 13th to 29th, 1936. Particulars may be obtained from M. Le Commissaire Général, 4, Rue Galilée, Paris, 16e.

First Brussels Aero Show.

The First International Aero Exhibition in Brussels will be held in May, 1937. Particulars may be obtained from the Sécretariat Général, 39, Rue D'Arlon, Bruxelles.

List of Members.

The List of Members published on January 1st, 1937, is now in course of preparation. Will members who have any alterations they wish to make in their addresses, designations, etc., kindly send in their corrections as soon as possible, as otherwise it will be assumed that their names, designations and addresses as now appearing in the List of Members are correct.

Acknowledgments.

The Council gratefully acknowledge the gift of back numbers of the Journal from Mr. W. S. Farren and Mr. F. Handley Page; and a gift of photographs of war-time (1914-1918) machines and a file of Press cuttings from Major D. H. Kennedy (Honorary Treasurer).

Additions to the Library.

The following books have been added to the Library during the month:—

The Analysis of Engineering Structures. A. J. S. Pippard and J. F. Baker.
Theory of Structures (4th Edition). A. Morley.
High Failure. John Grierson.
The Collected Papers of Rhys Jenkins. Newcomen Society.
Airplane Design (2nd Edition). E. P. Warner.
Snow Structure and Ski Fields. G. Seligman.
The Medical Examination for Fitness for Flying (Royal Air Force and Civil).
Résumé of Commercial Information, Series 7, No. 2, May-August, 1936.
Instruction Book for the Avro "Trainer," Type 621.
Transactions of the Institution of Naval Architects, 1936.
Proceedings of the Institution of Automobile Engineers, 1935-1936.
Journal of the Institute of Metals, No. 1, 1936 (Volume LVIII).
Metallurgical Abstracts of the Institute of Metals, Series II, Volume II, 1935.
Technical Report of the Aeronautical Research Committee:—
Vol. I.—Aerodynamics.
Vol. II.—Seaplanes, Structures, Engines, Materials, etc.
R. and M. No. 1697. Full-Scale Tests of Landing Flaps on a Percival Gull. J. E. Serby and P. A. Hufton.
The Modern Book of Aeroplanes. W. H. McCormick.

Technical Publications of the International Tin Research and Development Council:—

Series A, No. 44. Micro-Elasticity in Crystals of Tin. B. Chalmers.
Series A, No. 45. The Retarding Effect of Stannous Salts on the Oxidation of Olein and Oils. Dr. Ing. S. H. Bertram.

Technical Notes of the N.A.C.A.:—

No. 563. Tank Tests of Models of Floats for Single-Float Seaplanes. First Series. J. B. Parkinson.
No. 564. Procedure for Determining Speed and Climbing Performance of Airships. F. L. Thompson.

No. 565. Influence of Fuel-Oil Temperature on the Combustion in a Prechamber Compression-Ignition Engine. H. C. Gerrish and B. E. Ayer.

No. 566. Tank Tests of a Model of the NC Flying-Boat Hull, N.A.C.A. Model 44. J. W. Bell.

No. 567. Tests of N.A.C.A. Airfoils in the Variable-Density Wind Tunnel. Series 230. E. N. Jacobs and R. M. Pinkerton.

No. 568. Calculated Effect of Various Types of Flap on Take-off over Obstacles. J. W. Wetmore.

No. 569. Boosted Performance of a Compression-Ignition Engine with a Displacer Piston. C. S. Moore and H. H. Foster.

No. 570. Effect of Changes in Tail Arrangement upon the Spinning of a Low-Wing Monoplane Model. C. H. Zimmerman.

No. 571. A Method of Estimating the Aerodynamic Effects of Ordinary and Split Flaps Similar to the Clark Y. H. A. Pearson.

Reports of the N.A.C.A.:—

No. 557. Preliminary Tests in the N.A.C.A. Free-Spinning Wind Tunnel. C. H. Zimmerman.

No. 561. Effect of Nozzle Design on Fuel Spray and Flame Formation in a High-Speed Compression-Ignition Engine. A. M. Rothrock and C. D. Waldron.

Reports of the Aeronautical Research Institute of Tokyo Imperial University:—

No. 141. On the Relation between the Performance and the Loudness of Sound of an Airscrew. J. Obata, S. Kawada, Y. Yosida and U. Yosida.

No. 142. Sputtered Palladium Films, Part I, Cracks and Crumples Caused by Organic Contaminations. S. Tanaka.

No. 143. Buckling of a Rectangular Plate with Four Clamped Edges Re-examined with an Improved Theory. K. Sezawa and W. Watanabe.

Forthcoming Events.

November 3rd.—Lecture before the Students' Section in the Library of the Society at 7 p.m., by Mr. J. V. Connolly, B.E., A.F.R.Ae.S., on "Technical Aeronautics in Australia." In the chair: Mr. Thurstan James.

November 3rd.—Lecture before the Hayes and District Model Aero Club, by Mr. A. C. Brown, A.F.R.Ae.S., on "The History of the Aeroplane."

November 5th.—Lecture before the Yeovil Branch by Commander R. R. Graham, on "The Navy and the Aeroplane."

November 5th.—Lecture before the Royal Grammar School, Newcastle-on-Tyne by Mr. J. Bell, A.R.Ae.S.I., on "The Aeroplane and its Uses."

November 6th.—Lecture before Wakefield Grammar School by Mr. G. C. F. Ely, on "Flying Boats and Seaplanes."

November 7th.—Visit of Students' Section to De Havilland Aircraft Company, Limited, Stag Lane Works, Edgware, at 3 p.m.

November 7th.—Lecture before Brighton College by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "A Trip into the Stratosphere."

November 11th.—Lecture before the Southampton Branch by Mr. E. Brook-Williams, on "Aerial Navigation."

November 12th.—Lecture before the Society by Dr. F. W. Lanchester, F.R.S., Hon. F.R.Ae.S., M.I.Mech.E., F.R.S.A., on "The Part Played by Skin Friction in Aeronautics," at 6.30 p.m., in the Lecture Theatre of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2.

November 13th-29th.—Paris Aero Show.

November 14th.—Lecture before Kingswood School, Bath, by Mr. W. D. Douglas, on "A Trip into the Stratosphere."

November 17th.—Lecture before Kingswood Grammar School, Bristol, by Mr. W. Brierley, A.F.R.Ae.S., on "A Trip into the Stratosphere."

November 19th.—Lecture before the Society by Mr. Nigel Norman, F.R.Ae.S., on "Aerodrome Design," at 6.30 p.m., in the Lecture Theatre of the Royal Society of Arts, John Street, Adelphi, W.C.2.

November 19th.—Lecture before the Coventry Branch by Mr. F. Tomlinson, on "Lorenz Radio Guiding System."

November 19th.—Lecture before the Yeovil Branch by Mr. J. Lankester Parker, A.F.R.Ae.S., on "Construction of Large Aeroplanes."

November 20th.—Students' Section Informal Supper, "Cheshire Cheese," Little Essex Street, W.C.2, at 8 p.m.

November 21st.—Lecture before Lincoln Engineering Society by Mr. J. T. Morton, A.F.R.Ae.S., on "The History of the Aeroplane."

November 21st.—Lecture before Mistley Place School, Manningtree, by Mr. H. T. Winter, on "The Aeroplane and its Uses."

November 23rd.—Lecture before Newcastle-under-Lyme School by Mr. A. N. Jackson, B.Sc., A.F.R.Ae.S., on "Training R.A.F. Pilots."

November 27th.—Lecture before King's School, Rochester, by Mr. C. P. Lipscomb, A.F.R.Ae.S., on "A Trip into the Stratosphere."

November 27th.—Dinner-Dance at the "King's Head" Hotel, Hertford Street, Coventry. (Coventry Branch.)

December 1st.—Lecture before the Students' Section in the Library, at 7, Albemarle Street, W.1, at 7 p.m., on "Stressed Skin Construction," by Mr. C. Moore, B.Sc., A.F.R.Ae.S. In the chair: Mr. I. J. Gerard, M.Sc., A.M.Inst.C.E., A.F.R.Ae.S.

December 3rd.—Lecture before the Yeovil Branch by Mr. E. W. Knott, M.I.A.E., M.S.A.E., on "Carburation and Engine Controls."

December 8th.—Meeting of Council in the Offices of the Society at 5.30 p.m.

December 9th.—Lecture before the Southampton Branch by Mr. W. E. Crook, A.F.R.Ae.S., on "Wireless Applied to Aircraft."

December 10th.—Lecture before the Society by Mr. A. Gouge, B.Sc., F.R.Ae.S., on "Civil Flying Boats," at 6.30 p.m., in the Lecture Theatre of the Royal Society of Arts. 18, John Street, Adelphi, W.C.2.

December 14th.—Lecture before the Derby Y.M.C.A. by Mr. C. Ainsworth Davis, B.Sc., on "Training R.A.F. Pilots."

December 15th.—Students' Section, Joint Meeting with the Institution of Automobile Engineers (Graduates' Section) and the Institution of Petroleum Technologists on "Fuels for Aero Engines," by Mr. C. H. Barton, M.A., in the Council Room of the Society of Motor Manufacturers and Traders, 83, Pall Mall, S.W.1, at 7.0 p.m.

December 15th-16th.—Associate Fellowship and Associate Membership Examinations, in the Library of the Society, at 7, Albemarle Street, London, W.1.

December 17th.—Lecture before the Society by Professor B. Melvill Jones, A.F.C., M.A., F.R.Ae.S., on "Profile Drag," at 6.30 p.m., in the Lecture Theatre of the Royal Society of Arts, John Street, Adelphi, W.C.2.

December 17th.—Lecture before the Coventry Branch by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "The Queer Side of Flying."

J. LAURENCE PRITCHARD, *Secretary and Editor.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES
DECEMBER, 1936

Library Closing.

The Library will be closed on Tuesday, December 15th, and Wednesday, December 16th, while the Associate Fellowship and Associate Membership Examinations are in progress.

Christmas Holidays.

The Offices of the Society will be closed on Friday, December 25th, and will be re-opened on Monday, December 28th.

Donations.

The Council have much pleasure in announcing that Mr. C. R. Fairey, M.B.E., F.R.Ae.S., Past-President of the Society, and Mr. F. Handley Page, C.B.E., F.R.Ae.S., Vice-President of the Society, have jointly agreed to give £750 a year for seven years to the Society. The object of this generous gift is to enable the Society to carry out as fully as possible its main object " the general advancement of aeronautical science and engineering " and to enable it to be placed on a self-supporting basis.

Conversazione, January 12th, 1937.

At their meeting on November 10th, the Council decided to hold a Conversazione on January 12th, 1937, the 71st anniversary of the foundation of the Society. Particulars will be sent to all members in the near future. The Conversazione will be held at the Science Museum, South Kensington, S.W.7, by kind permission of the Director, Lieut.-Colonel E. E. B. Mackintosh. The function on January 12th next and in future will be separated from the Wilbur Wright Memorial Lecture, which will be held as usual during the last week in May. The Council hope that members will make a note of the date and will make every effort to attend.

Council Meeting.

A meeting of the Council was held on Tuesday, November 10th, in the Offices of the Society.

Present: Mr. H. E. Wimperis (President) in the chair; Major J. S. Buchanan, Major G. P. Bulman, Mr. H. Roxbee Cox, Mr. A. H. R. Fedden, Professor F. T. Hill, Professor G. T. R. Hill, Mr. W. O. Manning, Mr. F. Handley Page (Vice-President), Dr. N. A. V. Piercy, Mr. O. E. Simmonds, Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—Announcement of donations to the funds of the Society; Report of the Finance Committee; Report of the Grading Committee; Joint Congratulatory Address with other Institutions to H.M. the King on the occasion of the Coronation; appointment of representatives on the British Standards Institution Technical Committee on Aircraft Nomenclature; appointment of representatives on a Special Committee of the Institution of Civil Engineers; proposed lecture by Dr. Hugo Eckener; Conversazione on January 12th, 1937.

Elections.

The following members were elected at the Council Meeting on November 10th, 1936:—

Associate Fellows.—Roland Frederic Bailey, L. Everett Baynes, James Allan Jamieson Bennett, David Wallace Bottle, Lawrence Percival Coombes, Michael Gerard Casey, Henry Peterson Fraser, John Percy Gott, Wilfrid Edmund Brailsford Hennesey, Cecil Edwin Kerr, John Harold Lees, Pietro Clemente Lombardini, Arthur Prescott, James Blackstone Taylor, Jnr.

Associates.—Anthony Bridgeman Gibbons, Peregrine Forbes Morant Fellowes.

Students.—Eric Sydney Allwright, Alfred Herbert Alwin Bastable, Arthur James Cowing, Harry Maurice Gallay, Arthur St. George Harris, Leighton Stuart Holt, Thomas Henry Lismer, Horace Michael Dermott Magill, Richard Vivian Peacock, Cecil Arnold Ridgewell, Hilbert Frederick William Roper, Ernest Alfred Sleigh, Albert George Smith, Norman Jesse Wadsworth.

Companions.—Paul Adorjan, Francis James Waters.

Elliott Memorial Prize.

The Elliott Memorial Prize has been awarded to Leading Aircraftsman J. C. Stead.

Change of Notation in the Society's Examinations.

The Society has decided to change the definitions and notations of the aerodynamic coefficients used in its examination papers. The new coefficients, as recommended by the Aeronautical Research Committee, will be defined in terms of the dynamic pressure of a fluid, following American and Continental practice. Thus the non-dimensional lift coefficient will be denoted to C'_L and will be given by the relation $C'_L = L / \frac{1}{2}\rho V^2 S$.

Similarly for C_D, C_m, etc., the new coefficients being double the K_L, K_D, K_m, etc., coefficients employed hitherto. Full definitions will, however, be given in the forthcoming examination papers until candidates have become familiar with the new notation.

Aeronautical Diaries.

Aeronautical Diaries for 1937 may be obtained from the Office, price 6/- for the wallet type, 2s. 6d. for the refill style with pocket, and 1s. 6d. plain diary with pencil. Postage is 3d. extra on each diary. The Society's crest is on each diary.

Lecture Programme—Second Half of the 1936-1937 Session.

1937.

January 14th.—" Magnesium Alloys," Dr. C. H. Desch.

January 28th.—" Plastic Materials for Aircraft Construction," Dr. N. A. de Bruyne.

February 11th.—" The Automatic Pilot," Mr. F. W. Meredith, B.A., and Mr. P. A. Cooke, O.B.E., M.C.

February 18th.—" Compression Ignition Engines for Aircraft," Mr. A. H. R. Fedden, M.B.E., M.I.A.E., M.S.A.E., F.R.Ae.S.

February 25th.—" Power Measurements in the Air," Mr. N. S. Muir, B.Sc., A.M.I.Mech.E.

March 11th.—" Airscrew Blade Vibration," Major B. C. Carter, M.I.Mech.E., F.R.Ae.S., A.R.C.Sc., D.I.C.

April 8th.—" Control Surface and Wing Stability Problems," Mr. A. G. Pugsley, M.Sc., A.M.I.Struct.E.

April 22nd.—" Power Plant Trends," Mr. G. J. Mead, A.F.R.Ae.S.

May 27th (Wilbur Wright Lecture).—" Turbulence," Dr. Theodor von Kármán, F.I.Ae.S.

Engineering Institute of Canada.

The Engineering Institute of Canada, with which the branches of the Society in Montreal and Ottawa are affiliated, is holding its semi-centennial celebrations on June 15th, 16th and 17th, 1937, at Montreal. At the meeting a series of technical papers dealing with the main branches of engineering will be read of international as well as Canadian note and interest. Luncheon meetings will be arranged at which addresses on more general subjects will be given by prominent

speakers, and many official delegates will be present from engineering societies in other countries.

Visits will be arranged to engineering works and other points of interest and special arrangements will be made for the entertainment of ladies. On Friday, June 18th, the meetings will be continued at Ottawa, the seat of the Dominion Government, where a programme of interest will be arranged.

The Engineering Institute has branches in Toronto, Hamilton and other important centres and arrangements will be made to receive delegates and others who visit these centres.

The Council will have an official representative of the Society attending the celebrations, and it is particularly requested that any member of the Society who is visiting Canada on that date will get in touch with the Secretary as soon as possible.

The Canadian Pacific Railway Company are making special arrangements for those who wish to visit Montreal at the time of the 50th Anniversary Celebrations of the Engineering Institute of Canada. The s.s. " Duchess of York " will leave Liverpool on Friday, June 4th, and return on Friday, July 2nd, 1937. A programme of sightseeing in Canada has been arranged. Full particulars may be obtained direct from the C.P.R. Offices in Trafalgar Square, London, S.W.1.

Acknowledgments.

The Council gratefully acknowledge the gift of a copy of " Jane's All the World's Aircraft " for 1919 from Mr. M. H. Volk, F.R.Ae.S., and the gift of lantern slides from Mr. J. F. Cuss, A.F.R.Ae.S.

Additions to the Library.

The Theory of Dimensions and its Application for Engineers. Dr. F. W. Lanchester.

War Over England. L. O. E. Charlton.

Convegno di Scienze Fisiche, Matematiche e Naturali, 30th September-6th October, Reale Accademia D'Italia.

Wellworthy Liners and Liner Castings.

Wellworthy Valves and Valve Seat Inserts.

Abridgments of Patent Specifications 420,001-440,000.

Tin Plate and Tin Cans in the United States, Bulletin No. 4 of the International Tin Research and Development Council.

Report of a Conference on Atmospheric Ozone held at Oxford, September 9th to 11th, 1936. Royal Meteorological Society.

Notes on the Behaviour of the Anemograph at Lizard. Professional Notes No. 73 of the Meteorological Office. (Compiled from Reports by M. J. Thomas, B.Sc.)

Upper Winds at Wadi Halfa (Sudan), by J. Durward, M.A. Professional Notes No. 72 of the Meteorological Office.

Dirigeables, 1909, de Louis Godard. Extrait du Journal " L'Aerophile."

The Official Account of the World Altitude Record, September, 1936. Bristol Aeroplane Company, Limited.

Annual Report, Lloyd's Register of Shipping, 1st July, 1935-30th June, 1936.

Brown's Nautical Almanac, 1937.

Air Mail, by F. V. Monk and H. T. Winter.

The Inverse Method for Tapered and Twisted Wings, by Professor R. C. J. Howland, M.A., D.Sc., and B. S. Shenstone, M.A.Sc., A.F.R.Ae.S. (Reprinted from the " Philosophical Magazine," July, 1936.)

Martin's Air Navigation. C. W. Martin.

Jane's All the World's Aircraft, 1936.

Mathematics for the Million. Lancelot Hogben.

The Law of Civil Aviation. N. H. Moller.

Reports and Memoranda of the Aeronautical Research Committee:—

No. 1698. Wind Tunnel Tests of the Characteristics of Wings, Flaps and their Wakes, by K. W. Clark, B.Sc., D.I.C., and F. W. Kirkby.

No. 1702. The Cowling of Cooling Systems, by R. S. Capon, O.B.E., B.A., F.R.Ae.S.

No. 1705. Variation of Exhaust Gas Temperature Along the Tail Pipe of a Moth Aircraft and the Effect of a Simple Silencer. A. W. Morley, M.Sc.

Publications of the Laboratorio di Aeronautica della R. Scuola di Ingegneria di Toro:—

No. 82. Campo Aerodinamico a Velocita Iperacustica Attorno a un Solido di Rivoluzione a Prora Acuminata. C. Ferrari.

No. 83. Misure di Elasticita Coll'Uso dei Pendoli Accoppiati. Dott. Ing. P. Cicala.

No. 84. Richerche Sperimentali Sulle Vibrazioni Flesso-Torsionali di un Modello di Ala Con Rigidezze Variabili. P. Cicala.

No. 85. Le Azioni Aerodinamiche sul Profilo Oscillante. P. Cicala.

No. 86. Il Sistema Elastico Pneumatico-Ammortizzatore All'atterraggio degli Aeroplani. Ing. Ezio Lorenzelli.

Forthcoming Events.

Dec. 1st.—Lecture before the Students' Section in the Library, at 7 Albemarle Street, W.1, at 7 p.m., on "Stressed Skin Construction," by Mr. C. Moore, B.Sc., A.F.R.Ae.S. In the chair; Mr. I. J. Gerard, M.Sc., A.M.Inst.C.E., A.F.R.Ae.S.

Dec. 3rd.—Lecture before the Yeovil Branch, by Mr. E. W. Knott, M.I.A.E., M.S.A.E., on "Carburation and Engine Controls."

Dec. 3rd.—Lecture before the Portsmouth Branch, by Major B. W. Shilson, F.R.Ae.S., on "Modern Air-Cooled Aero Motors."

Dec. 5th.—Lecture before Berkhamsted School, by Mr. M. Langley, M.I.Ae.E., A.M.I.N.A., on "A Trip into the Stratosphere."

Dec. 8th.—Meeting of Council in the Offices of the Society at 5.30 p.m.

Dec. 9th.—Lecture before the Southampton Branch, by Mr. W. E. Crook, A.F.R.Ae.S., on "Wireless Applied to Aircraft."

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Dec. 15th.—Students' Section, Joint Meeting with the Institution of Automobile Engineers (Graduates' Section) and the Institution of Petroleum Technologists on "Fuels for Aero Engines," by Mr. C. H. Barton, M.A., in the Council Room of the Society of Motor Manufacturers and Traders, 83, Pall Mall, S.W.1, at 7 p.m.

Dec. 15th and 16th.—Associate Fellowship and Associate Membership Examinations in the Library of the Society, at 7, Albemarle Street, London, W.1.

Dec. 17th.—Lecture before the Society, by Professor B. Melvill Jones, A.F.C., M.A., F.R.Ae.S., on "Profile Drag," at 6.30 p.m., in the Lecture Theatre of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2.

Dec. 17th.—Lecture before the Coventry Branch, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "The Queer Side of Flying."

Dec. 17th.—Lecture before the Yeovil Branch, by Wing Cmdr. T. R. Cave-Browne-Cave, F.R.Ae.S., on "Noise in Aircraft."

Dec. 31st.—Lecture before the Yeovil Branch, by Mr. W. E. W. Petter, A.F.R.Ae.S., on "Some Reflections on the Paris Aero Show."

J. LAURENCE PRITCHARD, *Secretary and Editor.*

PUBLICATIONS

OF THE

ROYAL AERONAUTICAL SOCIETY

with which is incorporated The Institution of Aeronautical Engineers.

Corrected to June, 1936.

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(NOTE.—A classified list of important articles published in the Journal from January, 1919, to June, 1936, is given in this pamphlet. The price of Journals which are more than one month old cannot be guaranteed, and an inquiry should be made before ordering.)

The Aeronautical Classics.

Reprints of the Work of the Early Pioneers on whose theories modern flight is based.

1. "Aerial Navigation," by Sir George Cayley (1809) ... ... O.P.
2. "Aerial Locomotion," by F. H. Wenham (1866) £1/1/0
3. "The Art of Flying," by Thomas Walker (1810) 1/6
4. "The Aerial Ship," by Francesco Lana (1670) 5/-
5. "Gliding," by Percy S. Pilcher (1897), to which is added the Aeronautical Work of John Stringfellow 2/6
6. "The Flight of Birds," by G. A. Borelli (1680) 1/-

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"Report of the Bird Construction Committee" (1911) 5/-

Transactions of the Royal Aeronautical Society.

Original Papers of a Fundamental Character in the Science of Aeronautics.

No.	Title	Price
1.	"The Calculation of Stresses in Aeroplane Wing Spars," by Arthur Berry, M.A.	5/-
2.	"Position Fixing in Aircraft during Long Distance Flights over the Sea," by Instructor-Commander T. Y. Baker, R.N., and Major L. N. G. Filon, D.Sc., F.R.S., late R.A.F.	5/-
3.	"Aero Engine Efficiencies," by Dr. A. H. Gibson	O.P.

REPRINTS.

The following reprints of important Papers read before the Society are available:

No.	Title	Price
2.	"Methods of Measuring Aircraft Performances," by Captain H. T. Tizard, 1917	1/6
3.	"The Screw Propeller in Air," by M. A. S. Riach, 1917	2/6
5.	"Commercial Aeronautics," by G. Holt Thomas, 1918	2/6
7.	"Steel Tubes, Tube Manipulation and Tubular Structures for Aircraft," by W. W. Hackett and A. G. Hackett, 1918	2/6
9.	"Design of Aeroplane Struts," by W. H. Barling, A.R.C.Sc., B.Sc., and H. A. Webb, M.A., 1918	2/6
10.	"Stress Optical Experiments," by Major A. R. Low, 1919	5/-
12.	"Struts of Conical Taper," by H. A. Webb, M.A., and Miss E. D. Lang, M.A., 1919	1/6
19.	"Valve Steels," by P. B. Henshaw, 1927	10/-
20.	"The Generation of Vortices in Fluids of Small Viscosity," by Dr. L. Prandtl, 1927	5/-
21.	"Recent Model Experiments in Aerodynamics," by E. G. Richardson, B.A., M.Sc., Ph.D., 1927	5/-
22.	"Parachutes," by Flight-Lieutenant F. O. Soden, 1927	2/6
23.	"Safety from Fire in Airships," by Wing-Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., A.M.I.Mech.E., 1927 ...	2/6
24.	"Secondary Stresses in Airship Hull Structures," by J. F. Baker, M.A., 1927	2/6
27.	"The Problem of the Long-Range Flying Boat," by Major J. D. Rennie, A.R.T.C., A.M.Inst.C.E., F.R.Ae.S.	5/-
28.	"Fog," by Captain F. Entwistle, B.Sc., 1928	5/-
29.	"Modern Developments in Aircraft Instruments," by Major C. J. Stewart, O.B.E., M.I.Mech.E., F.R.Ae.S., M.I.A.E., 1928 ...	5/-
30.	"Experiments on Model Airscrews at High Tip Speeds," by G. P. Douglas, M.C., D.Sc., 1928	5/-
31.	"The Variable Pitch Airscrew," by H. S. Hele-Shaw, D.Sc., LL.D., F.R.S., M.Inst.C.E., and T. E. Beacham, B.Sc., A.C.G.I., A.M.Inst.C.E., 1928	5/-
32.	"The 16th Wilbur Wright Memorial Lecture (Slots)," by F. Handley Page, C.B., F.R.Ae.S., 1928	5/-
33.	"Notes on a Family of Similar Flying Boats," by C. Dornier, 1928	5/-

No.	Title	Price
34.	"The Use of Light Alloys in Aircraft from the Point of View of Corrosion," by H. Sutton, M.Sc., A.F.R.Ae.S., 1928	5/-
35.	"The Testing of Adhesives for Timber," by W. D. Douglas, F.R.C.Sc.I., A.M.I.E.E., A.F.R.Ae.S., and C. B. Pettifor, B.Sc., 1929	5/-
36.	"The Machinery Installation of Airship R.101," by Wing-Commander T. R. Cave-Browne-Cave, C.B.E., A.M.I.Mech.E., A.M.I.N.A., F.R.Ae.S., 1929	5/-
37.	"Steel Tubes Manipulation and Tubular Structures for Aircraft," by W. W. Hackett, and "Stainless Steel and Iron," by W. Hackett Junr., 1929	2/6
38.	"Weight of Aircraft," by Major T. M. Barlow, M.Sc., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S., 1929	5/-
39.	"Air-Cooled Engines in Service," by A. H. R. Fedden, F.R.Ae.S., 1929	5/-
40.	"The Streamline Aeroplane," by B. Melvill Jones, A.F.C., M.A., F.R.Ae.S., 1929	3/6
41.	"The Flutter of Aeroplane Wings," by R. A. Frazer, F.R.Ae.S., 1929	5/-
42.	"Monoplane or Biplane," by W. S. Farren, F.R.Ae.S., 1929 ...	5/-
43.	"The Helicogyre," by V. Isacco, 1929	5/-
44.	"The Cruise of the Royal Air Force Far East Flight," by Group-Captain H. M. Cave-Browne-Cave, D.S.O., D.F.C., F.R.Ae.S., 1929	5/-
45.	"Airscrew Body Interference," by C. N. H. Lock, M.A., A.F.R.Ae.S.	5/-
46.	"R.101," by Lieut.-Col. V. C. Richmond, O.B.E., B.Sc., F.R.Ae.S.	5/-
47.	"The External Forces on an Airship Structure, with Special Reference to the Requirements of Rigid Airship Design," by H. Roxbee Cox, Ph.D., D.I.C., A.F.R.Ae.S.	5/-
48.	"French Wind Tunnel Methods," by A. Lapresle	5/-
49.	"Handling and Mooring of Airships," by Major G. H. Scott, C.B.E., A.F.C., F.R.Ae.S.	2/6
50.	"Prospects of Civil Aviation in East Africa," by F. Tymms, M.C., A.F.R.Ae.S.	5/-
52.	"Science in Relation to Regulating and Promoting Civil Aviation," by the Hon. Wm. P MacCracken, Jun.	5/-
53.	"Strength of Transverse Frames of Rigid Airships," by Miss H. M. Lyon, M.A., A.F.R.Ae.S.	5/-
53A.	"Modern Aerodynamical Research in Germany," by J. W. Maccoll, B.Sc., Ph.D., A.F.R.Ae.S.	5/-
54.	"Ten Years' Gliding and Soaring in Germany," by Dr. W. Georgii ...	5/-
55.	"Resistance of Air-Cooled Engines" and "The Townend Ring," by Major F. M. Green, O.B.E., A.M.Inst.C.E., F.R.Ae.S., and Mr. H. C. H. Townend, A.F.R.Ae.S.	5/-
56.	"The Equilibrium of Loaded Impeller Blades, with Special Reference to the Strength of Thin Metal Airscrews," by P. A. Ralli, A.F.R.Ae.S.	5/-
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No.	Title	Price
58.	"Night Air Mails," by Captain Carl Florman	5/-
59.	"Noise," by A. H. Davis, D.Sc.	5/-
60.	"Research Work at the D.V.L.," by Wilh. Hoff	5/-
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63.	"The Influence of Atmospheric Humidity and Other Factors upon the Static Lift of Airships," by W. G. Bird, M.A. (Oxon), A.F.R.Ae.S.	5/-
64.	"A Contribution to the Analysis of Primary Stresses in the Hull of a Rigid Airship," by L. Chitty, A.F.R.Ae.S., and R. V. Southwell, F.R.S., F.R.Ae.S.	5/-
66.	"Flight in Nature and in Science," by R. Giacomelli, A.F.R.Ae.S.	5/-
67.	"An Engineer's Conception of Matter and its Application to Materials of Construction," by E. W. Stedman, F.R.Ae.S.	5/-
68.	"New Methods of Research in Aeronautics," by H. E. Wimperis, C.B.E., M.A., F.R.Ae.S.	5/-
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Characteristics of Design Affecting Production, Operation and Maintenance	P. Bishop	April, 1920

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An Empirical Formula for Aeroplane Strength	A. J. Sutton Pippard	April, 1920
Safety in Flight	R. K. Bagnall-Wild	August, 1920
Incidence Wires	Miss H. P. Hudson	September, 1920
Development of Giant Aircraft in Germany	Anon.	Feb. & Mar., 1921
The Handley Page Wing	F. Handley Page	June, 1921
The Design of Aeroplane Control Surfaces	H. B. Irving	October, 1921
Staggered Spar Sections	Miss H. P. Hudson	October, 1921
The Development of the Fighting Aeroplane	F. M. Green	February, 1922
Specialised Aircraft	W. D. Beatty	March, 1922
The Design of a Commercial Aeroplane	G. de Havilland	July, 1922
Stability Calculations in the Process of Design	J. D. North	October, 1922
The Case for Metal Construction	J. D. North	January, 1923
Estimation of Weight of Aeroplane Parts	E. P. Warner	January, 1923
Two-Dimensional Aerofoil Theory	Muriel Glauert	July, 1923
Aeronautic Research and Aircraft Design	J. S. Ames	August, 1923
Metal Aeroplane Construction	Hugo Junkers	September, 1923
Control of Aeroplanes at Low Speeds	B. Melvill Jones	October, 1923
Design of Marine Aircraft in Relation to Seaworthiness	D. F. Lucking	November, 1923
The Effect of Variable Gearing on Performance	Annie D. Betts	November, 1923
The Development of High-Speed Aircraft	R. H. Mayo	March, 1924
Large All-Metal Seaplanes	A. Rohrbach	December, 1924
Some Notes on the Design of Commercial Aircraft from the Operational Point of View	Major R. H. Mayo	May, 1927
Aeroplane Controls: Faults and Diagnosis	W. G. Gibson	March, 1927
Schneider Trophy Machine Design	R. J. Mitchell	September, 1928
Monoplane or Biplane	W. S. Farren	July, 1929
Undercarriage Developments	G. H. Dowty, A.F.R.Ae.S., M.I.Ae.E.	February, 1930
Certificates of Airworthiness	H. B. Howard, B.A., B.Sc., A.F.R.Ae.S.	May, 1930
Elements of Detail Design	F. Radcliffe, B.Sc., A.M.I.A.E., A.R.Ae.S.I.	November, 1930
Wheel Brakes and Undercarriages	S. Scott-Hall	May, 1932
Wing Construction	H. J. Stieger	October, 1932
Some Notes on the Design of Aeroplane Control Surfaces and Control Systems	W. F. Dowsett	November, 1932
Aeroplane Covers and Wheels	F. Fellowes	February, 1933
Note on the Application of Berry Functions to the Determination of Initial Stress	W. E. Dumbrill, F.R.Ae.S.	April, 1933
The Nature of the Torsional Stability of a Monocoque Fuselage	K. Sezawa	May, 1933
Duralumin Applied to Aircraft Construction	W. H. Lewis, A.F.R.Ae.S.	August, 1933
The Strength of Aeroplane Wing Spars with End Load Varying on Any One Bay	Captain J. Morris, A.F.R.Ae.S.	June, 1934
Winter Landing Gear	Squadron Leader A. Ferrier, A.F.R.Ae.S.	June, 1934
Some Developments in Aircraft Construction	H. J. Pollard, A.F.R.Ae.S.	July, 1934
The Trend of Development in Military Aircraft	Sir E. W. Petter, M.I.Mech.E.	February, 1935
The Aerodynamic Characteristics of Aircraft Skis and the Development of an Improved Design	J. J. Green and G. J. Klein	August, 1935
Transversely Loaded Framework Members	N. J. Hoff	August, 1935
Some Notes on Aircraft Possibilities	Captain F. S. Barnwell, B.Sc., O.B.E., A.F.C., F.R.Ae.S.	March, 1936
Retractable Undercarriages	G. H. Dowty, M.I.Ae.E., A.F.R.Ae.S.	April, 1936
Notes on the Strength of Stressed Skin Fuselages	G. F. Wallace, A.F.R.Ae.S.	April, 1936

Engines and Fuels

Possible Lines of Development in Aircraft Engines	H. R. Ricardo	March, 1921
The Instalment of an Aeroplane Engine	A. J. Rowledge	March, 1921
The Effect of Atmospheric Pressure and Temperature upon Performance	E. G. Ritchie	August, 1921
Engine Installation	R. K. Bagnall-Wild	April, 1922
Special Light-Weight Aero Engines	A. E. L. Chorlton	April, 1922
The Importance of Low Weight and Low Fuel Consumption	A. J. Rowledge	August, 1922
The Stability of Aero Engines	J. Morris	April, 1923
The Thermodynamics of Aircraft Engines	H. R. Ricardo	February, 1924
Radial Air-Cooled Engines	A. H. R. Fedden	April, 1924
Fuel Economy in Flight	H. T. Tizard	October, 1924
Reliability of Aircraft Engines	J. D. Siddeley	March, 1925
Light Aeroplane Engine Development	Lieut.-Col. L. F. R. Fell	April, 1925
The Evaporative Cooling of Aero Engines and the Condensation of Exhaust Gas for Water Recovery	T. R. Cave-Browne-Cave	January, 1926
Installation Problems of Radial Air-Cooled Engines	A. H. R. Fedden	January, 1926
Modern American Aircraft Development	Charles L. Lawrance	July, 1926
Supercharged Aero Engines	R. F. R. Pierce	October, 1926
Aero Engine Fuels of To-day and To-morrow	Colonel The Master of Sempill, A.F.C., A.F.R.Ae.S.	December, 1926
Dynamic Forces in Aircraft Engines	Major B. C. Carter	April, 1927
The Articulated Connecting Rod	E. J. Fearn	February, 1927
The Articulated Connecting Rod—An Alternative Method for Finding Accelerations	W. S. Farren	March, 1927
The Effect of Reduced Intake-Air Pressure and of Hydrogen on the Performance of a Solid-Injection Oil Engine	G. F. Mucklow, M.Sc.	January, 1927
The Supercharging of Aircraft and Motor-Vehicle Engines	A. H. R. Fedden	October, 1927
Magnetos	A. P. Young	August, 1927
Water-Cooled Aero Engines	A. A. Rubbra	January, 1928

ENGINES AND FUELS—(Continued).

High-Speed Compression-Ignition Engine Research	H. B. Taylor	July, 1928
Schneider Trophy Engine Design	Captain G. S. Wilkinson	September, 1928
Repair of Aero Engines	Wing-Comdr. I. G. V. Fowler	November, 1928
Air-Cooled Engines in Service	A. H. R. Fedden	April, 1929
Aero Engines in Flight	R. J. Penn	May, 1929
Cirrus Mark III.	A. N. Caple	May, 1929
Engine Performance Testing	Wing-Commander G. B. Hynes, D.S.O., R.A.F.	August, 1929
The Lubrication of Aircraft Engines	F. A. Foord, A.F.R.Ae.S.	December, 1929
Fuels and Dopes for Aircraft Engines	Dr. A. E. Dunstan and Dr. F. B. Thole	April, 1930
Water-Cooled Aero Engines (Six Years' Progress)	A. J. Rowledge	July, 1930
The Resistance of Air-Cooled Engines	Major F. M. Green, O.B.E., M.Inst.C.E., F.R.Ae.S.	October, 1930
The Townend Ring	H. C. H. Townend, B.Sc., A.F.R.Ae.S.	October, 1930
The Development and Progress of the Aero Engine	H. R. Ricardo, F.R.S., F.R.Ae.S.	December, 1930
Recent Developments in Engine Cooling	Captain Andrew Swan	March, 1931
The Origin and Development of Heavy-Oil Aero Engines	D. R. Pye, M.A., F.R.Ae.S.	April, 1931
Fuel and Modern Methods of Testing	H. C. Tett	July, 1931
Injection, Ignition, and Combustion in High-speed Heavy Oil Engines	S. J. Davies, Ph.D., M.Sc., and E. Giffen, M.Sc.	October, 1931
The Turbo-Compressor and the Supercharging of Aero Engines	Flying Officer F. Whittle	November, 1931
Fuels for Aircraft Engines	F. R. Banks, A.F.R.Ae.S.	February, 1932
The Critical Diameter of the Carburettor Choke in Supercharged Engines	E. J. Fearn	May, 1932
Some Problems connected with High-Speed Compression-Ignition Engine Development	C. B. Dicksee	September, 1932
Aero Engine Accessories	W. L. Taylor	October, 1932
Some Notes and Observations on Petrol and Diesel Engines	H. R. Ricardo, F.R.Ae.S.	June, 1933
Some Notes on the Pressure Piping Effects on Fuel Injection	C. W. Lawson, B.Sc.	August, 1933
Engine Cooling Research	R. McKinnon Wood, F.R.Ae.S.	September, 1933
The Compression Ignition Engine as the Rival of the Petrol Engine	C. B. Dicksee	January, 1934
Possible Future Developments of Air-Cooled Aero Engines	A. H. R. Fedden, F.R.Ae.S.	March, 1934
Ethyl: Some Information on the Use and Advantages gained by the Employment of Tetraethyl Lead in Fuels for Aviation Engines	F. Rodwell Banks, F.R.Ae.S.	April, 1934
Engine Cowling with Special Reference to the Air-Cooled Engine	J. D. North, F.R.Ae.S., M.I.Ae.E.	July, 1934
The Cowling and Cooling of Radial Air-Cooled Aircraft Engines	R. B. Beisel, A. L. MacClain and F. M. Thomas	July, 1934
Causes of Detonation in Petrol and Diesel Engines	G. D. Boerlage and Dr. J. D. Van Dyck	December, 1934
The Thurston Rotor Cowl for Air-Cooled Engines. A new Method for Cooling and Reducing Head Resistance	A. P. Thurston, D.Sc., F.R.Ae.S.	May, 1935
Liquid-Cooled Engines—Design and Application to High-Speed and other Aircraft	Captain A. G. Forsyth	June, 1935
Ice Formation in Carburettors	W. C. Clothier, M.Sc., Wh.Sch., A.M.I.Mech.E.	September, 1935
Fuels for Aircraft Engines	E. L. Bass, M.I.A.E., M.I.Ae.S., M.S.A.E., A.F.R.Ae.S.	October, 1935
Cooling Problems, with Particular Reference to the Work of the 24ft. R.A.E. Tunnel	G. P. Douglas, M.C., D.Sc., A.F.R.Ae.S.	February, 1936

Gliders and Light Aeroplanes

Gliders and Light Planes	A. Ogilvie	November, 1923
Gliders: Their History and Uses	W. H. Sayers	May, 1924
The R.Ae.C. Light Aeroplane Competitions	J. S. Buchanan	December, 1924
Some Considerations in the Design of a Light Aeroplane	Flight Lieut. N. Comper	May, 1925
Notes on the Flying Qualities of the Light Aeroplane compared with Larger Types	Squadron Leader R. A. de H. Haig	September, 1925
By Light Aeroplane to India	Captain T. M. Stack	October, 1927
Flying and Maintenance from the Owner's Point of View	Squadron-Leader N. M. Probyn	February, 1930
Ten Years' Gliding and Soaring in Germany	Dr. W. Georgii	September, 1930
The Meteorological Aspects of Gliding and Soaring Flight	Captain F. Entwistle, B.Sc.	June, 1931
The Development, Design, and Construction of Gliders and Sailplanes	A. Lippisch	July, 1931
Cloud Formation and its Effect upon Gliding	Sir Gilbert Walker	August, 1933

Helicopters

The Problem of the Helicopter	L. Damblanc	January, 1921
Helicopters	John Case	Oct. & Nov., 1922
Air Travel, with Special Reference to Helicopters	F. M. Green	July, 1923
The Development of the Autogyro	Senor de la Cierva	January, 1926

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The Theory of the Autogyro	H. Glauert, M.A., F.R.Ae.S.	June, 1927
The Helicogyre	M. Isacco	July, 1929
The Autogyro	J. de la Cierva, A.F.R.Ae.S.	November, 1930
Modern Developments of the Helicopter	Capt. R. N. Liptrot, A.F.R.Ae.S.	July, 1931
Wing Beats, III	J. D. Batten	February, 1933
The Case for Vertical Flight	H. H. Platt	June, 1934
The Autogyro Rotor as a Sail	Lt.-Col. J. T. C. Moore-Brabazon, F.R.Ae.S., M.C., M.P.	September, 1934
New Developments of the Autogiro	Senor Juan de la Cierva, F.R.Ae.S.	December, 1935

History

The Langley Machine & the Hammondsport Trials	Griffith Brewer	December, 1921
The Work of S. P. Langley	L. Bairstow	November, 1922
Leonardo da Vinci as a Pioneer of Aviation	I. B. Hart	May, 1923
Leonardo da Vinci's MS. on the Flight of Birds	I. B. Hart	June, 1923
Sir George Cayley as a Pioneer of Aeronautics	J. E. Hodgson	August, 1923
The Development of High-Speed Aircraft	R. H. Mayo	March, 1924
Gliders: Their History and Uses	W. H. Sayers	May, 1924
French Aeronautical Societies	W. Lockwood Marsh	November, 1924
The Aerodynamics of Leonardo da Vinci	R. Giacomelli, A.F.R.Ae.S.	December, 1930
Growth of Aviation	C. R. Fairey, M.B.E., F.R.Ae.S.	January, 1931
Flight in Nature and Science	R. Giacomelli	July, 1932
An Echo of the 1868 Exhibition	W. O. Manning, F.R.Ae.S.	March, 1933
Extracts from Aeronautical and Miscellaneous Notebook of Sir George Cayley		June, 1933
Fifty Years Ago	W. O. Manning, F.R.Ae.S.	January, 1934
Sir George Cayley, the Founder of British Aeronautical Science	J. E. Hodgson, Hon.F.R.Ae.S.	May, 1936

Instruments and Navigation

Air Navigation	H. E. Wimperis	August, 1919
The Static Head Turn Indicator for Aeroplanes	Sir Horace Darwin	December, 1919
Flying Over Clouds and Commercial Aeronautics	B. Melvill Jones	May, 1920
An Acoustic Tension Meter	A. H. Stuart	February, 1923
Aerial Navigation	A. P. Rowe	September, 1923
Some Recent Developments in Aircraft Instruments	H. E. Wimperis	Jan. & Feb., 1924
Practical Navigation of Aircraft	Captain F. Tymms	May, 1925
Modern Developments in Aircraft Instruments	Major C. J. Stewart	June, 1928
Testing Aeroplane Controls	H. L. Stevens, A.F.R.Ae.S.	February, 1931
Tables for Use in Aero Navigation by Astronomical Methods	P. F. Everitt	February, 1931
Air Navigation	Captain N. Macmillan	April, 1933
On a New Aircraft-Sextant for Use with Visible Horizon	L. Becker, Ph.D.	August, 1933

Materials

Steels Used in Aero Work	W. H. Hatfield	July-Sept. '17 (Reprinted October, 1925)
Shop Practice in Respect to Aircraft Steel	H. P. Philpot	March, 1919
Fabric and Dope	F. W. Aston	May, 1919
Metal Construction of Aircraft	A. P. Thurston	September, 1919
Aluminium Alloys for Aeroplane Engines	F. C. Lea	November, 1919 (Reprinted Aug., 1925)
Various Types of Timber Splices	G. W. C. Kaye and J. Hudson Davies	September, 1920
Wire Cables	Walter A. Scoble	October, 1920
Sockets for Wire Cables	Walter A. Scoble	November, 1921
The Elastic Constants of Spruce as Influenced by Moisture	H. Carrington	December, 1922
The Case for Metal Construction	J. D. North	January, 1923
Fatigue in Metals	C. F. Jenkin	March, 1923
Consolidated Wood	W. R. Turnbull	July, 1923
Metal Aeroplane Construction	Hugo Junkers	September, 1923
Some Materials in Aircraft Construction	J. D. North	April, 1924
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Dopes and Fabrics	J. E. Ramsbottom	May, 1924
Large All-Metal Seaplanes	A. Rohrbach	December, 1924
Some Remarks on the Proof Stress	E. Skerry	May, 1926
Notes on Magnesium and Its Alloys	W. R. D. Jones	December, 1926
Valve Steels	P. B. Henshaw	March, 1927
Testing of Aircraft Materials	W. Sutcliffe	April, 1927
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Defects and Deterioration	W. G. Gibson	November, 1927
Alloy and Stainless Steels	J. Hopcroft	January, 1928
The Use of Light Alloys in Aircraft from the Point of View of Corrosion	H. Sutton	January, 1929
The Testing of Adhesives for Timber	W. D. Douglas & C. B. Pettifor	February, 1929
Steel Tubes, Tube Manipulation and Tubular Structures for Aircraft	W. W. Hackett	March, 1929
Stainless Steel and Iron	W. Hackett, Junr.	March, 1929
The Inspection of Metals and their Alloys	L. W. Johnson, M.C.	June, 1930
The Development of Materials for Aircraft Purposes	W. Rosenhain	August, 1930
Protection of Metal Parts of Aircraft against Corrosion	H. Sutton, M.Sc., A.F.R.Ae.S.	January, 1932
Mechanical Tests of Aircraft Structural Components	I. J. Gerard	September, 1932

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Manufacture and Use of Light Alloys	W. C. Devereux, A.F.R.Ae.S.	February, 1933
The Structure of Timbers in Relation to their Uses	F. W. Jane, B.Sc.	January, 1934
Light Alloys for Aeronautical Purposes, with Special Reference to Magnesium	L. Aitchison, B.Sc.	May, 1934
The Corrosion and Protection of Magnesium and its Light Alloys	G. D. Bengough, D.Sc., and L. Whitby, M.Sc.	May, 1934
Ferrous Metallurgy in Relation to Aircraft	Dr. W. H. Hatfield	July, 1935
A Research into Tests for Materials used in Cold Pressing Operations, with special reference to the Fluid-Pressure Cupping Test	H. J. Gough, M.B.E., D.Sc., F.R.S., and G. A. Hankins, D.Sc.	November, 1935
Cold Pressing and Drawing—The Metallurgical Aspect	C. H. Desch, D.Sc., F.R.S.	November, 1935
New Researches on the Drawing of Cylindrical Shells	Dr. Ing. G. Sachs	November, 1935
The Corrosion of Elektron Alloy AM503 by Leaded Fuels	G. D. Bengough, M.A., D.Sc., and L. Whitby, Ph.D., M.Sc., A.I.C.	December, 1935
The Theory of Alloy Structures	Professor W. L. Bragg, O.B.E., M.A., Sc.D., F.R.S.	June, 1936

Medical

Medical Aspects of Aviation	L. E. Stamm	January, 1919
Some Physical and Psychical Effects of Altitudes	C. A. Swan	January, 1920
The Human Machine in Relation to Flying	Martin Flack	December, 1920
Some Medical Aspects of Air Transport	C. B. Heald	June, 1925
Man and the Machine	Group-Captain Martin Flack, C.B.E., M.B., M.A.	May, 1927
Preventive Medicine in its Relation to Aviation	E. Goodwin Rawlinson	April, 1932
The Physiological Limitations of Flying	Wing Comdr. G. S. Marshall	May, 1933

Meteorology

The Supply of Meteorological Information	H. G. Lyons	July, 1919
The Meteorology of the English Channel	H. D. Grant	January, 1921
Meteorology in the Service of Aviation	G. Dobson	May, 1921
The Effect of Temperature and Altitude of Aerodromes on the Taking-Off of Aeroplanes	P. G. Gundry	June, 1921
The Effect of Meteorological Conditions on Aircraft	G. H. Scott & V. C. Richmond	March, 1924
Thunderstorms and Aviation	Dr. G. C. Simpson	January, 1925
The Beneficence of Atmospherics	R. A. Watson Watt	February, 1925
Fog	Captain F. Entwistle	May, 1928
Some Notes on Temperature Gradients in Iraq	E. J. D. Townesend, B.A., A.F.R.Ae.S.	October, 1928
Air Transport in Fog	F. W. Meredith	February, 1931
Meteorology of India	J. H. Field, M.A.	August, 1934
Turbulence near the Ground	Wilhelm Schmidt	May, 1935
The Prevention of Ice Accretion	B. Lockspeiser, M.A.	January, 1936

Miscellaneous

The Rigging of Aeroplanes	R. J. Goodman Crouch	April, 1919
Some Kite-Balloon Experiments	Griffith Brewer	January, 1920
Aircraft *versus* Submarines	L. H. Strain	April, 1921
Ground Engineering	H. W. S. Outram	May, 1921
Parachutes: Saving Life in Air Wrecks	T. Orde Lees	July, 1921
The Problem of Flapping Flight	H. Chatley	September, 1921
Aeroplanes in Tropical Countries	H. R. M. Brooke-Popham	November, 1921
Notes on the Storage of Aircraft	P. V. Hoare	June & July, 1922
Radiological Inspection Work	V. E. Pullin	September, 1922
Some Technical Aspects of Aviation in Canada	E. W. Stedman	September, 1922
The Present Position of Aerial Photographic Survey	H. H. Thomas	July, 1924
Sound Reception	W. S. Tucker	August, 1924
The British Aviation Mission to the Imperial Japanese Navy	The Master of Sempill	September, 1924
Further Notes on Aviation in Canada	E. W. Stedman	September, 1924
The Flight of Birds	Colonel Fullerton	October, 1925
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The Schneider Trophy Race, 1925	Major J. S. Buchanan	July, 1926
Relationship of Physics to Aeronautical Research	H. E. Wimperis	November, 1926
The Training of Aircraft Apprentices	Wing-Commander C. D. Breese, A.F.C.	March, 1927
Aeronautics	General A. Guidoni	May, 1927
Erection and Rigging of Aeroplanes	W. G. Gibson	August, 1927
Polar Exploration and Survey by Air	S. Scott Hall, D.I.S., A.F.R.Ae.S.	September, 1927
Parachutes	Flight-Lieut. F. O. Soden	October, 1927
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Safety Devices for Aircraft	M. L. Bramson	April, 1928
Ground Transport for an Air Organisation	Flt.-Lt. R. E. H. Allen	July, 1928
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The Technical Development of the Aeroplane	J. D. North	January, 1929
The Immediate Aims of Aeronautical Research	H. E. Wimperis	January, 1929
Some Aspects of the Production Problem in Aircraft	F. Sigrist	March, 1929

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Weight of Aircraft	T. M. Barlow	April, 1929
Notes on the Aeronautical Show, Chicago, Dec., 1928	F. S. Barnwell	May, 1929
An Historical Survey of Italian Aeronautics ...	R. Giacomelli, A.F.R.Ae.S. ...	October, 1929
My Flight to Australia	Sq.-Leader J. H. L. B. Hinkler, A.F.C., D.S.M., R.A.A.F. ...	November, 1929
Air Photography Surveys	J. Durward, F.R.G.S., F.R.P.S., A.F.R.Ae.S.	April, 1930
Some Technical Notes on Canadian Aviation ...	Sq.-Leader D. C. M. Hume, R.C.A.F.	May, 1930
Jet Propulsion for Aircraft	E. G. Richardson, B.A., Ph.D., D.Sc., A.F.R.Ae.S.	January, 1931
The Method of Least Work and the Stressing of Aeroplane Structures	F. G. Evans, B.Sc.	July, 1931
Noise	A. H. Davis, D.Sc.	August, 1931
The Development of Aircraft Manufacture ...	Glenn L. Martin, F.R.Ae.S. ...	October, 1931
Safety Devices in Wings of Birds	Lt.-Comdr. R. R. Graham, R.N.	January, 1932
Aircraft and the Fire Problem	R. A. Denne	May, 1932
Catapults and Catapulting of Aeroplanes	P. Salmon	September, 1932
An Engineer's Conception of Matter and its Application to Materials of Construction ...	E. W. Stedman	October, 1932
How Insects Fly	R. E. Snodgrass	February, 1933
Air Survey	J. S. A. Salt	March, 1933
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Aircraft in Relation to Petroleum Technology: Use for Survey and Transport	H. Hemming, F.R.Ae.S. ...	October, 1933
Development of Aviation Lighting	Major R. H. S. Mealing, A.R.Ae.S.I.	August, 1934
Houston-Everest Flight	Air Comdr. P. F. M. Fellowes, D.S.O.	August, 1934
Silent Flight of Owls	R. R. Graham	October, 1934
The Training of an Aeronautical Engineer ...	Professor A. J. Sutton Pippard, M.B.E., D.Sc., M.Inst.C.E., F.R.Ae.S.	February, 1935
How to Obtain an Aero Patent	An Honorary Fellow	March, 1935
On a Simple Method for Solving Simultaneous Linear Equations by a Successive Approximation Process	J. Morris, B.A.	April, 1935
The Stressing of Rigid-Jointed Frames	Captain J. Morris, B.A. ...	June, 1936

Piloting and Performance

Flying Over Clouds and Commercial Aeronautics...	B. Melvill Jones	May, 1920
A Comparison of the Flying Qualities of Single and Twin-Engined Aeroplanes	R. M. Hill	December, 1920
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Landing Aeroplanes in Fog	Flight-Lieut. H. Cooch	June, 1926
Experimental Flying from the Pilot's Point of View	R. L. Ragg	November, 1926
Performance Testing and Analysis	R. S. Capon	February, 1927
The Practical Side of Performance Testing of Aircraft	Squadron-Leader T. H. England	January, 1928
The Reduction of Performance Tests	H. L. Stevens	November, 1928
Experimental Test Flying	C. F. Uwins	May, 1929
Range of Aircraft	C. R. Fairey, M.B.E., F.R.Ae.S.	March, 1930
The Art of Flying Landplanes and Seaplanes ...	Captain N. MacMillan, A.F.C., A.F.R.Ae.S.	April, 1930
High Speed Flying	H. E. Wimperis, C.B., C.B.E., F.R.Ae.S.	November, 1931
The Refuelling of Aircraft in Flight	J. H. B. Larrard, A.F.R.Ae.S.	December, 1931
Some Factors Affecting the Range of Aircraft with Special Reference to Height	A. E. Woodward-Nutt and A. F. Scroggs	August, 1932
Training of Pilots and Instructors	Air Cmdr. J. E. A. Baldwin ...	November, 1932
Civil Primary Training	Major H. G. Travers, D.S.C. ...	April, 1933
Training the Airplane Pilot	Col. F. P. Lahm	November, 1933
A New Method for Calculating the Climbing Speeds of Aeroplanes of Great Climbing Capacity ...	Captain G. Otten	February, 1935
Engineering Problems in Aircraft Operation at High Altitudes	R. E. Johnson and R. F. Gagg	April, 1936

Research and Experiment

Full-Scale Aeroplane Experiments	W. S. Farren	February, 1919
From Model to Full-Scale in Aeronautics	H. Levy	June, 1919
The Work of the Advisory Committee for Aeronautics	Sir R. T. Glazebrook	September, 1920
Scientific Methods in Aeronautics	G. I. Taylor	September, 1921
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The Importance of Research in Aeronautics ...	Council of the R.Ae.S.	February, 1922
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On Research and Other Matters	S. Heckstall Smith	August, 1922
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